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# 1980 Land Cover for the Puget Sound Region

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# 1980 Land Cover for the Puget Sound Region

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Prepared for:

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National Aeronautics and
Space Administration

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## PREFACE

This report was written by Dr. Frank V. Westerlund, Mr. James R. Eby and the UW Collaborator. Verification and photointerpretation assistance was provided by Ms. Malgorzata Mycke-Dominko, Polish Remote Sensing Center and the University of Warsaw, Geography Department. Also, the Washington State Department of Game via Mr. Larry Brewer assisted us in verification of some of the vegetation classes. Mr. Kerry Brooks and Mr. Albert England provided student assistance. Ms. Razi Rezazadeh typed the report.

The authors take full responsibility for the report. We wish to thank all contributors whether named or not. We anticipate that some twenty-five state and local planning and resources management agencies will find the report and the products useful, now and in years to come.

R. Duane Shinn

UW Collaborator

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## 1.0 EXECUTIVE SUMMARY

The material in this report was assembled to show the detail of a long and deliberate process for the establishment of Landsat applications in a multi-purpose classification of land cover. The history of the Puget Sound land cover project has not been written completely anywhere else. The compilation of several research projects and reports has been done herein. There are basic methodologies explained in enough detail to serve as teaching materials for those who want to do land cover classification with the Video Information Communications and Retrival/Image Based information System (VICAR/IBIS hereinafter called VICAR). Included is a verification procedure for use with digital format land cover maps by cluster sampling.

The audience for this report is an extension of the participants in the process. Planners in state and local planning and resources agencies are the individuals who will profit most from the materials assembled. The history prior to 1979 is important in the documentation of the questions and answers facing the analysts of Landsat data in future applications. A multi-purpose, spectral classification of land cover is a basic information layer in a geo-information system. Resources managers and land use planners see the need for this area extensive information layering. As important as the land cover map is the requirement for a verified product. Since new technology is suspect, verification has to be taken into account. In the case of Landsat, the data is considered volatile; and in the case of planners there is a hesitancy

to rely on the product of statistical routines in computers.

Several significant findings can be enumerated:

1. Land cover classification for multiple purposes can be done with the spectral data obtained from different Landsats, by different analysts, with different software systems, on different computers and years apart from each other with satisfactory replication of the results.
2. VICAR has been tested as a State of Washington data processing system from a remote location from the computer center. In this case, the Remote Sensing Applications Laboratory at the University of Washington was able to use the VICAR vended by the Washington State University Computing Service Center.
3. A full scene was classified for land cover using VICAR for the first time. The FASTCLAS for a full scene job took about 23 minutes of computing time on the Amdahl 470 V-8.
4. Classification of the preceding Landsat scene by spectral signature extension was done for the first time on VICAR.
5. The size of the user involvement in a single project was unequalled in the Pacific Northwest and maybe elsewhere.
6. A high level of accuracy (over 90% at 95 confidence) was established for Level I land cover in the final product.

7. Utility of the information has been attractive to other researchers after the classification was finished and beyond the list of local participants found in Appendix B.
8. A public library with a collection of files containing information layers of land cover, census tracts, elevation strata, game management units, river basins and other related data has been established.

# 2.0 HISTORY OF THE PUGET SOUND LAND COVER PROJECT 1975-81

## 2.1 Background/Overview

The Puget Sound Land Cover Project originated as one of 23 disciplinary and site-specific applications of remote sensing technology under the Pacific Northwest Land Resources Inventory Demonstration Project (LRIDP), sponsored jointly by the Pacific Northwest Regional Commission (PNRC), NASA, and the U.S. Geological Survey. The effort was continued along with several other activities under the follow-on Landsat Application Program (LAP) with the same sponsors. Further continuation under the present University Consortium Interchange and in several spin-off activities has attained something of an independent status for the Puget Sound Land Cover Project. It is important to review here the LRIDP and LAP programs which established the current project's approach and direction as a vehicle for technology transfer.

The origins of the LRIDP are traced to the Remote Sensing Symposium held at the Oregon Museum of Science and Industry in Portland in November 1973. Formation of an Ad Hoc Task Force on Remote Sensing in the Pacific Northwest composed of state agency and university representatives was the start. During the following year, this group surveyed ongoing remote sensing activities and data needs in the Pacific Northwest (PNW). A report was submitted to the PNRC requesting

support for a program that would assist orderly development of remote sensing applications and facilities to serve needs of the PNW region and take advantage of emerging Federal systems for earth observation and ground data processing.

In late 1974, in response to this initiative, the PNRC identified a need in the three PNW states for more accurate and current land use and natural resource information upon which to base land planning and resource management decisions. A Land Resource Inventory Task Force (later renamed the Technology Transfer Task Force) with representatives from Idaho, Oregon, and Washington was established to pursue a remote sensing demonstration project addressing the goals of the Commission and the specific information needs of state and local agencies.

Based on prior discussions and offers of assistance by Federal agencies, the Task Force requested the technical support of NASA, through the Ames Research Center at Moffett Field California. Support was also requested from the USGS Earth Resources Observation Systems (EROS) Program based at Reston, Virginia and at the EROS Data Center at Sioux Falls, South Dakota. Further assistance was requested from the USGS Geography Program at Reston, which included a small research group based at San Jose State University. This group, already engaged in applications of Landsat digital processing, was relocated in an office at NASA-Ames under an agreement between NASA and USGS.

In January 1975 the PNRC approved and funded the Task Force's plan for a three and one-half year Land Resources Inventory Demonstration Project. The five phases of the project are outlined below.

2.1.1 Land Resources Inventory Demonstration Project, 1975-78

2.1.1.1 Phase I - Preparation of a Regional Map Series

Primarily for display and discussion purposes, this phase consisted of producing a Level I land use/cover map of each state by photointerpretation of Landsat imagery. These maps were accompanied by maps at the same scale showing soils, drainage basins, land ownership classes and energy features.

2.1.1.2 Phase II - Training of User Agency Personnel, Preparation of Examples of Data Analysis and Products

This phase included discipline-specific workshops held at NASA-Ames and the EROS Data Center for state and local agency personnel. At the Urban Discipline Workshop held at Ames in July 1975, preliminary digital land cover classifications of the Puget Sound and Boise areas were displayed. These examples were prepared by the USGS Geography Program staff using the EDITOR software system, but without specific ground truth training data or other user input.

2.1.1.3 Phase III - Demonstration of Applications Using Digitally Processed Landsat Data

This primary demonstration and technology transfer phase involved digital analysis of Landsat data in the context of user-defined problems and information needed for decision-making. Twenty-three applications or sub-projects were undertaken, distributed among the three states, 45 state and local agencies, and the identified disciplines of agriculture/ water resources, forestry, rangeland management, urban planning, noxious week control, and surface mining. Each project was based on an identified test site or sites, a user agency group, a technical support group and coordinators. Also, a Task Force-arproved project plan stating objectives, technical approach, tasks and procedures, schedule and output products was required. Agency personnel participated in project design, ground truth data collection, some "hand-on" data analysis and evaluation of products. Documentation of user participation was coordinated by the State Task Force Representatives. Technical support for digital data analysis (hardware/software facilities, analysts, support services) was provided by NASA and USGS under the overall direction of NASA-Ames Discipline Coordinators.

The Puget Sound Land Cover Project originated and was carried to its first stage of completion as an LRIDP Phase III demonstration project (known as the Puget Sound Urban Discipline Demonstration Project). This was a cooperative effort of ten local and regional government agencies, the Washington Planning and Community Affairs Agency and the University of Washington,

with support by PNRC, NASA, and USGS. Two, full-scene digital land cover classifications were produced from 1974 and 1975 Landsat data. Map and tabular products were evaluated by the participating agencies relative to a number of potential applications.

2.1.1.4 Phase IV - Operational System Investigation

This phase built on experience gained in the Phase III demonstrations to make an assessment of user needs and interest in developing operational remote sensing data analysis capabilities in the PNW region and to study feasible options for such developments. Elements included a user needs study, an analysis of Landsat data processing systems, assessment of candidate systems, and a survey of existing computer facilities in the PNW.

2.1.1.5 Phase V - Evaluation and Recommendations

Tha Task Force drew on evaluations of the individual demonstrations, results of the Phase IV studies, and an independent economic evaluation, to make the recommendation that the PNRC undertake a second, three-year project. The central objective was implementation and testing of a digital Landsat analysis capability in each of the three PNW states. It had been determined that significant applications development and utilization of Landsat technology had occurred. But user demand was not yet sufficient to sustain the full development

and operating costs of an analysis capability.

The recommended follow-on project was a progressive step in which basic capability would be provided to each state. This objective was pursued through the transfer of software programs and their installation on existing state computers, along with user training on these systems and continued demonstrations to apply this capability to agency problems in a near-operational mode.

2.1.1.6 LRIDP Approach to Technology Transfer

The LRIDP was widely recognized for its innovative approach to technology transfer and had major influence on the design of demonstration programs nationally, including NASA's Regional Remote Sensing Applications Program, of which the NASA-Ames Western Regional Applications Program (WRAP) is a component.

Basic philosophy and operating principles of the LRIDP included the following:

A. Program is user driven.

B. Active Cooperation among Federal, state and local government agencies and universities in a multi-state region.

C. Participant roles:

User agencies define real problems, commit personnel and resources.

PNRC provides project management and support.

Federal agencies provide technical support.

D. Opportunities provided for planning and resource management agencies to extract, utilize and evaluate information derived from an advanced technology (satellite and aircraft remote sensing and related data management systems).

E. Evaluation of applications within the realistic agency setting of:

   Governmental procedures

   Agency charters and responsibilities

   Information needs for resource management

   Personnel training

   Technical requirements

F. Evaluation of alternative technical and institutional mechanisms for continued and effective use of remote sensing technology by user agencies.

Funding arrangements and requirements for shared commitment of resources served the project's purposes by creating incentives for all participants. NASA and USGS with their contractors provided all the technical support for data analysis and personnel training, which were conducted almost entirely at their facilities (except for some work conducted at ESL, a NASA contractor, and at Oregon State University-ERSAL). This technical support was provided through internal funding mechanisms of NASA and USGS.

PNRC funded project management by the Technology Transfer Task Force and also paid for the travel of state and local agency personnel. Travel to NASA Ames Research Center and the EROS Data Center for analytical work, field data collection, and travel to state and discipline review meetings was included. PNRC funding was a necessary catalyst for the project, since state and local agencies are very limited in travel funds and often prohibited from traveling out-of-state. The PNRC travel funding produced the high level of interaction among agencies, states and disciplines that made the project vital.

Agency participation was an in-kind commitment of personnel time, resources and existing data, and was used to define information needs, plan projects, receive training, participate in analysis, utilize products, and evaluate results. As a general rule there was no direct transfer of funds between these groups of participants (NASA/USGS, PNRC and user agencies).

PNRC and NASA funding did support involvement of universities in several areas. These included technical support, special studies in several project Phases, and project evaluation through a University Advisory Committee.

### 2.1.2 Landsat Application Program, 1978-80

Objectives of the follow-on PNW Landsat Application Program (LAP) were to:

A. Establish and demonstrate an operational capability in the region to extract and utilize information derived from satellite and other remotely sensed data;

B. Demonstrate the operational utility of Landsat through new and continuing participation of state and local agencies; and

C. Strengthen planning and natural resource management process through incorporation of satellite data in existing information systems.

To accomplish each of these objectives, the following activities were undertaken:

A. Hardware/Software Acquisition, Transfer, Installation and Development

1. Installation of the NASA/JPL VICAR/IBIS software system on existing state computers in Washington and Idaho. In Washington, the VICAR/IBIS software routines were installed in late 1978 on the Amdahl V-6 computer system at the Washington State University Computing Service Center (WSUCSC). The software was later converted to the Center's upgraded Amdahl 470 V-8 system.

2. Establishment of an interactive digital image display capability in Washington and Idaho. In Washington, an Interactive Image Processing Facility (IIPL) was installed in Olympia in 1980. This consisted of a DEC 1134A minicomputer,

a Stanford Technology Corporation Model 70E Image Display System with color monitor and trackball, peripherals including terminal, printer, tape and disc drives, operating system software and STC image processing software. In May 1981, this system was moved to a new Digital Image Analysis Laboratory (DIAL) at WSUCSC which centralizes both interactive and VICAR/IBIS batch operations. Although the two are not directly linked and major image processing tasks are carried out in VICAR/IBIS on the Amdahl, the interactive facility is used for data review at many points in an analysis process and for some stand-alone analysis.

3. Support for further development of the PIXSYS software system already operational at the Oregon State University, Environmental Remote Sensing Applications Laboratory (ERSAL).

B. Technical Services.

NASA- Additional software programming support required for for conversions between systems. Consultation on applications activities.

USGS- Intergovernmental transfer of a person from EROS Data Center to PNRC to assist technical management of applications activities and provide coordination with other Federal agencies.

C. Education/Training

Workshops at the Jet Propulsion Laboratory, NASA-Ames, and

universities on the use of VICAR/IBIS and other software systems and analysis techniques.

D. Operational Applications Activities

Eleven new or continuing LRIDP follow-on application activities were conducted under LAP. The selection of these was limited to applications judged to have solid project design, certainty of achievable results, and potential for operational continuation. Three of these LAP applications related to or were an integral part of the Puget Sound Land Cover Project. These included:

1. City of Tacoma. Completion of a program to install a data management system that incorporates Landsat-derived land cover data along with other physical statistical data.

2. Washington Department of Game. Ruffed grouse habitat inventory of Western Washington employing vegetative cover data from the 1974 Landsat classification produced for the LRIDP Puget Sound Urban Demonstration combined with elevation data.

3. UW-RSAL VICAR/IBIS Demonstration to assemble existing Puget Sound Landsat data, land cover classifications, digitized maps and related files using the VICAR/IBIS software system based at WSUCSC, for use by state and local planning agencies.

Program support changed somewhat under LAP as compared to LRIDP. Consistent with the general program philosophy and progression toward independent, operational use of remote sensing technology in the region, PNRC continued to provide management and coordination through the Technology Transfer Task Force and a contractor. However, the major responsibility for technical implementation of applications activities shifted from NASA/USGS to the user agencies themselves and the organizations hosting the operational system installations in each state. NASA technical support concentrated on implementation of the systems, including the software transfers and specification of the interactive hardware/software systems, with consultation on applications activities.

Because some user agencies involved in LAP applications had to make larger commitments of resources than under LRIDP, including purchase of computing services at operational installations, PNRC made direct grants to several agencies. The universities and agencies where the installations were located were also funded to conduct training workshops and support the applications activities. All these grants were provided on a 50/50 cost-sharing basis, so agencies were still required to commit substantial resources of their own. Travel was no longer funded by PNRC, and was subsumed under the agencies' contribution.

The three LAP activities that represented the Puget Sound Land Cover Project at this stage (City of Tacoma, Washington Department of Game, and UW-RSAL VICAR/IBIS Demonstration) were each the recipient of a PNRC grant. The University of Washington was selected for management of the third activity because of its prior involvement in the LRIDP Puget Sound Urban Discipline Project, technical capabilities and access to the WSUCSC VICAR/IBIS system, and because the University was in a position to coordinate activities among the large user community in the Puget Sound area. During LAP this community expanded to 16 agencies. The UW-RSAL contribution was in lieu of grants to individual agencies, however, agency participants were required, along with the University, to commit resources (travel, personnel time, etc.) matching the PNRC funding.

### 2.1.3 Post-LAP Continuation, 1980-81

The PNRC-funded LAP application activities related to Puget Sound were concluded at the end of 1979. On March 1, 1980, the University of Washington Remote Sensing Applications Laboratory received funding from NASA-Ames for a continuation of the project under a University Consortium Interchange Agreement titled "1980 Land Cover Classification for the Puget Sound Region." Under this, and a subsequent Interchange Agreement extending from December 1, 1980 to September 30, 1981, a new land cover classification of 1979 Landsat data was undertaken,

with the cooperative participation of the state and local agency community. The main purpose of the present report is to document work accomplished under these agreements, which is covered in detail in the subsequent chapters.

### 2.1.4 Background of University of Washington Involvement

The University of Washington Remote Sensing Applications Laboratory (UW-RSAL), as a collaborator with NASA-Ames in these Interchange Agreements, has assumed a major responsibility for coordinating and assisting continued application of Landsat data among state and local agencies in the Puget Sound region. Therefore, it is appropriate to note the origins of this involvement, which predate the Land Resources Inventory Demonstration Project.

In 1971, the USGS EROS Program contracted with the University of Washington Department of Urban Planning for a three-year program titled "Urban and Regional Planning Utilization of ERTS-Type Data in the Pacific Northwest," Dr. Arthur L. Grey, principal investigator. The UW Department of Geography was also a participant, and parallel EROS contracts with the UW Department of Civil Engineering and the Washington Department of Natural Resources investigated engineering and state land management applications. With this support, RSAL was established in late 1971 as a research unit of the Department of Urban Planning.

The EROS-funded program involved the identification and development of land use planning applications of remote sensing data, based on a review of past research, laboratory investigation, and a series of meetings and cooperative pilot projects with agencies. Investigations concentrated on photointerpretive use of imagery from high-altitude aircraft, ERTS simulator flights, and, after it launch in 1972, the ERTS (Landsat-1) satellite. Pilot projects were undertaken with San Juan County (San Juan Island land cover inventory), King County/Port of Seattle (Seattle-Tacoma International Airport community land use change study), Skagit County (nuclear power plant secondary development siting), Snohomish County (shoreline inventory under Shorelines Management Act), Puget Sound Council of Governments (river basins land cover mapping), and the Washington Oceanographic Institute (petroleum marine terminals siting study). In 1974-75, the Puget Sound Council of Governments contracted with RSAL for a remote sensing training/pilot project involving the training of PSCOG personnel and a test of photointerpretive land use inventory in Kitsap County, as a prelude to later digital analysis. Through these activities, by 1975, RSAL had established working relationships with a number of local agencies in the Puget Sound area and had conferred with such state agencies as the state Planning and Community Affairs Agency, the Department of Ecology, the Department of Natural Resources and the Oceanographic Institute. Participation

in two Washington State Remote Sensing Conferences in 1973 and 1974 had furthered these contacts, as had a short course in planning applications of remote sensing offered for agency personnel by RSAL in May 1975.

RSAL participated in the OMSI Conference, was represented on the Ad-Hoc Remote Sensing Committee, and was involved in LRIDP planning sessions with PNRC Task Force and NASA officials. In early 1975, Dr. Duane Shinn, RSAL Co-Director, was appointed first chairman of the LRIDP University Advisory Committee. RSAL personnel attended the Urban Discipline Workshop at NASA-Ames in July 1975. By participating in the planning of the Puget Sound Urban Discipline project an RSAL staff member, Dr. Frank Westerlund, became involved in the first classification effort employing 1974 Landsat data. RSAL provided photointerpretive facilities for use by agency participants throughout the project. The laboratory was also involved in project review and evaluation, and hosted the Urban Discipline Review Meeting in October 1976.

During 1976-77 RSAL was a collaborator with NASA-Ames in the Phase IV User Needs Study, which interviewed and surveyed the information needs and anticipated uses of Landsat data by all agencies participating in the LRIDP, including those involved in the Puget Sound Project. In the summer of 1977, the laboratory conducted a demonstration of remote access use of the EDITOR Landsat data processing software system. By means of a WATS

line telephone link to NASA-Ames, connection was made with the ARPANET computer network. With initiation of the LAP program in mid-1978, RSAL personnel including Dr. Westerlund (on Intergovernmental Assignment to NASA) were involved in technical meetings in Olympia and NASA-Ames leading to the decisions to establish VICAR/IBIS at WSUCSC as the operational Landsat data processing system in Washington State. Dr. Shinn and Mr. James Eby of RSAL attended a VICAR/IBIS training course at JPL in May 1979. Further training in the WSUCSC WYLBUR file management system was provided by workshops at Pullman and Puyallup. Access to VICAR/IBIS at WSUCSC was established by means of a CRT terminal in RSAL, connected to a remote job entry (RJE) station located at the UW Urban Data Center. This set-up was exercised in the Fall of 1979 in the PNRC-funded LAP VICAR/IBIS Demonstration.

With this background of cooperative involvement and technical preparation, RSAL was prepared in 1980 to undertake a continuation of the Puget Sound Land Cover Project and provide the major technical support for a new Landsat land cover classification of the Puget Sound region.

The role of a university in technology transfer includes many elements and is not as clearly defined as that of Federal agencies or of user agencies. A university may function at different times as a user, an applications researcher and developer, a program evaluator, a provider of facilities and technical

assistance, and a technology transfer agent. Flexibility in carrying out these various roles is a strength of a university in technology transfer, as is its permanence within a region as a center of knowledge and expertise. In this respect, it is hoped that the university participants in the LRIDP/LAP and subsequent programs will have an important further role in sustaining remote sensing applications in the Pacific Northwest.

## 2.2 The LRIDP Puget Sound Urban Demonstration Project, 1975-78

### 2.2.1 Project History

In July 1975, representatives of ten local planning agencies in the Puget Sound region, the Washington Planning and Community Affairs Agency, and UW-RSAL, met with NASA and USGS staff at NASA Ames Research Center for an Urban Discipline Workshop and project planning meeting. A Puget Sound Urban Discipline Group was constituted, with participating agencies shown in Table 2.2-1. Coordinator for the group was the Washington representative on the LRIDP Task Force, Mr. Michael McCormick, also representing WPCAA. In two planning sessions, this group defined a common set of needs for land information and outlined an analytical approach for a demonstration project.

Initial expression of information needs was varied and included: (1) generalized land use and land cover data; (2) delimitation of urban areas and urban-rural boundaries; (3) change detection, especially in urban fringe areas; (4) identification of non-urban

Table 2.2-1

Participating Agencies

Puget Sound Urban Demonstration Project

Local Government Agencies

City of Tacoma Planning Department

Pierce County Planning Department

King County Department of Community Development, Division of Planning

Snohomish County Planning Department

Kitsap County Planning Department

Jefferson - Port Townsend Regional Council

Mason Regional Planning Council

Thurston Regional Planning Council

Puget Sound Council of Governments (PSCOG)

Municipality of Metropolitan Seattle (METRO)

State Agencies/Universities

Washington Planning and Community Affairs Agency

University of Washington, Department of Urban Planning, Remote Sensing Applications Laboratory

Supporting Agencies

Pacific Northwest Regional Commision, Technology Transfer Task Force

NASA Ames Research Center, Technology Applications Branch

U.S. Geological Survey, Earth Resources Observation Systems Program and Geography Program

land within urbanized areas; (5) location and measurement of disturbed land; and (6) shoreline studies. These types of information were needed to develop land use data bases at a level of generality suitable for area-wide planning, for rapid update of land use and cover data, for input to regional transportation and activity allocation models, for use in water quality planning under Section 208 of the Federal Water Pollution Control Act Ammendments, for monitoring special situations such as the growth impact of the Trident Submarine Support Facility in Kitsap County, and for general use in community area planning and communication with the public and decision-makers.

Considering the resources available for the project, along with other factors, it was determined that effort should be concentrated on one basic product that could serve several, though not necessarily all of these needs, and provide information of value to all the participants. This was determined to be a general land use/cover classification of a 20,000 sq. km. area of the Puget Sound region including all or parts of eight counties. This area was contained within one Landsat scene, occupying about two thirds of the scene area. A cloud-free scene obtained by Landsat-1 on June 13, 1974 (1690-18245) was selected.

Consensus was first reached on a desired classification typology, representing a union of user information needs with respect to category content and detail. It was recognized that this

classification might not be wholly obtainable. However, it was useful as a guide and statement of objectives. The two-level classification typology is shown in Table 2.2-2.

A project plan was drafted, outlining: (1) objectives of the demonstration; (2) interests, expectations, and commitments of each participating agency or organization; (3) classification output products to be prepared for all participants; (4) unique deliverable products for each agency; and (5) project schedule. This plan was revised several times over the next year before it was finalized as an LRIDP Demonstration Plan document.* The plan is included as Appendix A.

The Puget Sound Urban Discipline Group selected two representatives, Mr. Tom Weber of the Kitsap County Planning Department and Dr. Frank Westerlund of UW-RSAL, to receive training and work with USGS and NASA personnel on initial development of the classification. Each user agency was assigned the task of identifying and mapping representative samples of the land cover types in its jurisdiction that could be used as training sites in the Landsat data analysis.

Work began at NASA Ames Research Center in August 1975 at the facility staffed and equipped by the USGS Geography Program.

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* Pacific Northwest Regional Commission, Land Resources Inventory Demonstration Project, Central Puget Sound Urban Land Inventory Demonstration Plan, October 1976.

Table 2.2-2

Land Cover Classification Typology Developed by the LRIDP Puget Sound Urban Group, Representing a Composite of Information Needs and a Product Goal for Landsat Data Analysis

RESIDENTIAL
- Single Family
  - Dense (greater than 9 du/acre)
  - Medium Density (5 to 9 du/acre)
  - Suburban Density (1 to 5 du/acre)
  - Residential Estate (1 to 3 acres/du)
- Multiple Family
  - Medium Density (less than 25 du/acre)
  - High Density (25 or greater du/acre)
- Mobile Home Parks

COMMERCIAL
- General Commercial
- Community Business

INDUSTRIAL
- Heavy
- Light
- Log Booms
- Large Buildings/Structures

OPEN SPACE
- Improved
- Unimproved

DISTURBED LAND
- Extractive Activities
  - Sand and Gravel Pits
- Sanitary Land Fill
- New Construction
- Other

AGRICULTURE
- Crop Land
  - General
  - Berry Crops
  - Green Houses
  - Fallow
- Pasture Land

FOREST
- Conifer
  - Mature
  - Immature
- Decidious
- Mixed Conifer-Decidious
- Clearcut (recently logged)
- Other (snow-rock-ice)

WATER
- Clear
- Water with Sedimentation
- Wetlands and Tidelands

Messrs. Leonard Gaydos and Willard L. Newland were the principal USGS analysts who provided training and guidance to the visiting user representatives, and completed the Landsat data analysis for the 1974 classification and a subsequent classification using 1975 data. Overall coordination of the technical support was provided by NASA-Ames. An LRIDP Urban Discipline Coordinator, Mr. Don Wilson, was assigned this responsibility in early 1976.

A complete technical description of the Landsat data analysis is contained in a paper by Gaydos and Newland titled, "Inventory of Land Use and Land Cover in the Puget Sound Region Using Landsat Digital Data."*

An image data analysis system implemented on several computers was employed. Central to this system was the software package EDITOR (ERTS Data Interpreter and TENEX Operations Recorder) developed over several years at the University of Illinois Center for Advanced Computation (CAC) with funding from NASA, USGS, USDA and U.S. Department of Defense. Four computers on the Advanced Research Project Agency National Computer Network (ARPANET) of the Department of Defense were used (Fig. 2.2-1), as follows:

1. An IBM 360/91 at the University of California at Los Angeles, used for geometric correction and reformatting.

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* Leonard Gaydos and Willard L. Newland, Journal of Research, U.S. Geological Survey, Vol.6, No.6, Nov.-Dec. 1978, p. 507-814.

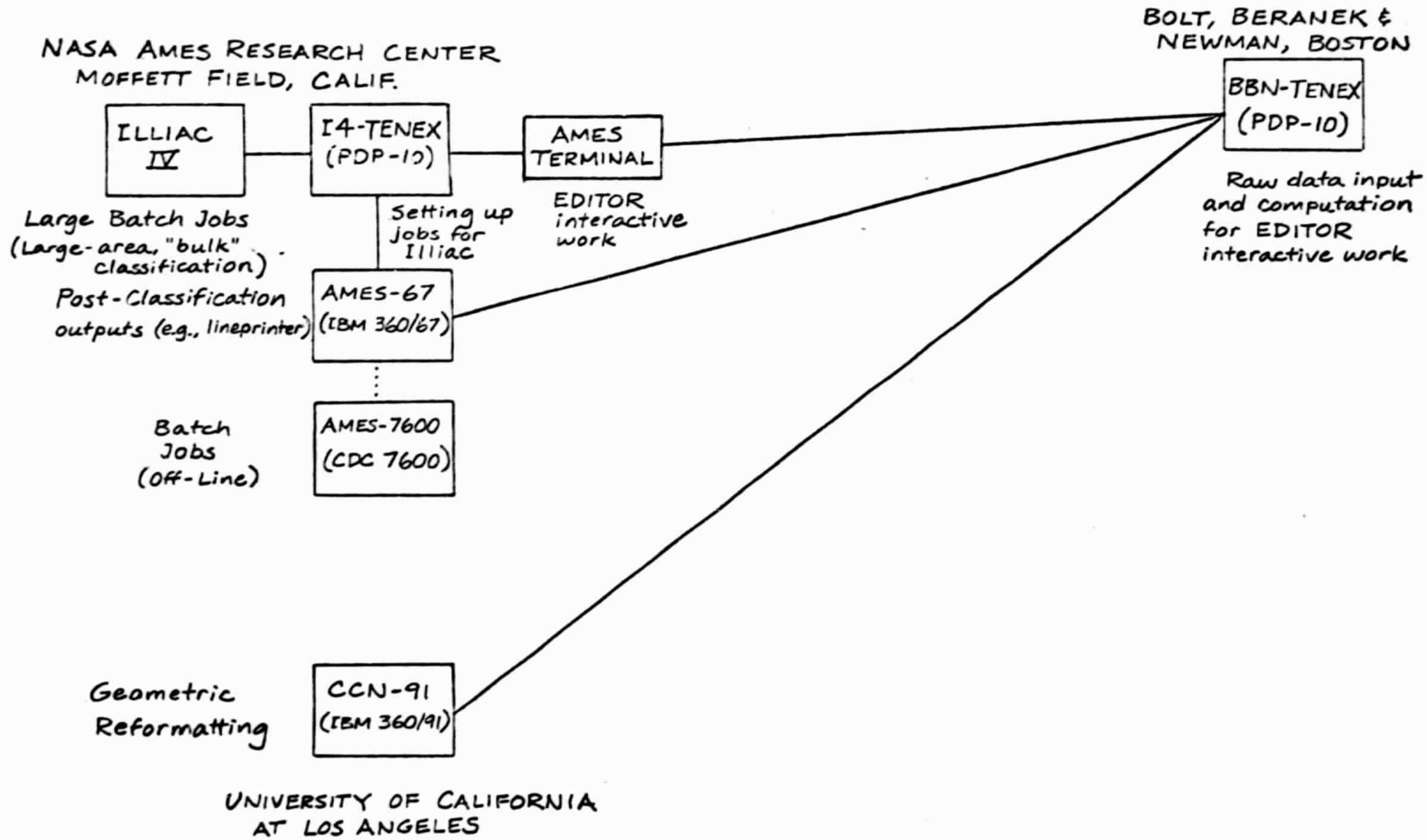


Figure 2.2-1 Portion of the Advanced Research Projects Agency Computer Network (ARPANET) Used for Landsat Data Processing at NASA Ames Research Center

Source: Mr. Leonard Gaydos, U.S. Geological Survey Geography Program, NASA Ames Research Center

2. A TENEX (modified DEC PDP-10) located at Bolt, Beranek and Newman, Inc. (BBN) in Boston, Mass. This computer provided an interactive data analysis capability through EDITOR.
3. The ILLIAC IV at NASA-Ames, a powerful, special-purpose parallel processing computer used for large cluster analysis and bulk data classification.
4. An IBM 360/67 at NASA-Ames, used to collect and display data processed elsewhere on ARPANET.

In addition, a CDC 7600 at Ames not on ARPANET was used to supplement the ILLIAC IV for bulk classification.

The overall processing sequence was as follows:

1. Reformatting a Landsat tape (CCT) at CAC for purposes of image rectification and geographic registration. Six control points identified on a Band 7 print at 1:500,000 scale and a USGS topographic map at 1:250,000 scale were used to establish a least-squares linear transformation between latitude-longtitude and pixel row column coordinate systems. The resulting parameters necessary for geometric rectification were applied to the original Landsat CCT acquired from EROS Data Center, using the IBM 360/91 at UCLA. Rows and columns were shifted so that pixels generated on the output tape were in a north-oriented coordinate system. No pixels were lost, replicated, or

resampled. After this first-order skew transformation, gray-scale displays could be produced on a lineprinter at approximately 1:24,000 scale. This allowed convenient comparison with USGS 7½' topographic maps, and conversion of geographic coordinates taken from maps to pixel coordinates within about four pixels of the correct position.

An improved, second-order transformation was achieved using 24 control points (mainly hydrographic features) on large scale maps to create a calibration file relating Landsat pixels and geographic coordinates to within one pixel. This file could be accessed at any time by EDITOR to relate map and image data. Further work, in preparation for matching color-coded graphic products of the classification to a map projection, involved modeling a grid of pixels in a Universal Transverse Mercator (UTM) system and using the second-order transformation to find the nearest pixel corresponding to each UTM grid intersection.

2. The transformed, reformatted tape was shipped to BBN, where it was mounted and run with the EDITOR software on the TENEX, on command from a lineprinter terminal at Ames, for development of classification statistics.

3. The classification statistics file was transferred from BBN to the Ames IBM 360/67 over ARPANET From there the file was either transferred to ILLIAC IV or punched onto cards that could be run on the Ames CDC 7600 to produce

a maximum likelihood spectral classification of all pixels.

4. The Ames IBM 360-67 was again used to group spectral classes into land cover classes and assign an alpha-numeric symbol to each for lineprinter map display. A distinctive color value was also assigned to each cover class for display on a Dicomed D47 film recorder. This was done by creating a three-file tape from the classification to control the exposure of each pixel successively through the blue, green, and red filters of the film recorder.

The major part of the classification work was step 3., the interactive phase of landsat data processing, conducted at the lineprinter terminal at Ames. Use of the EDITOR program involved an interactive process described as "guided clustering," a hybrid technique employing elements of both supervised and unsupervised classification. Figure 2.2-2 is a generalized schematic showing the steps in this process. Some 200 sample area representing different cover classes in the desired typology had been identified by the participating agencies, based on ground truth or other information available for their jurisdictions, and delineated on maps furnished to the working group. These areas were interpreted and verified on U-2 CIR photographs, taken in September 1975 (NASA-ARC Flight 75-153). The areas were re-delineated on 7 1/2-minute USGS maps in the form of rectangular polygons incorporating only land cover

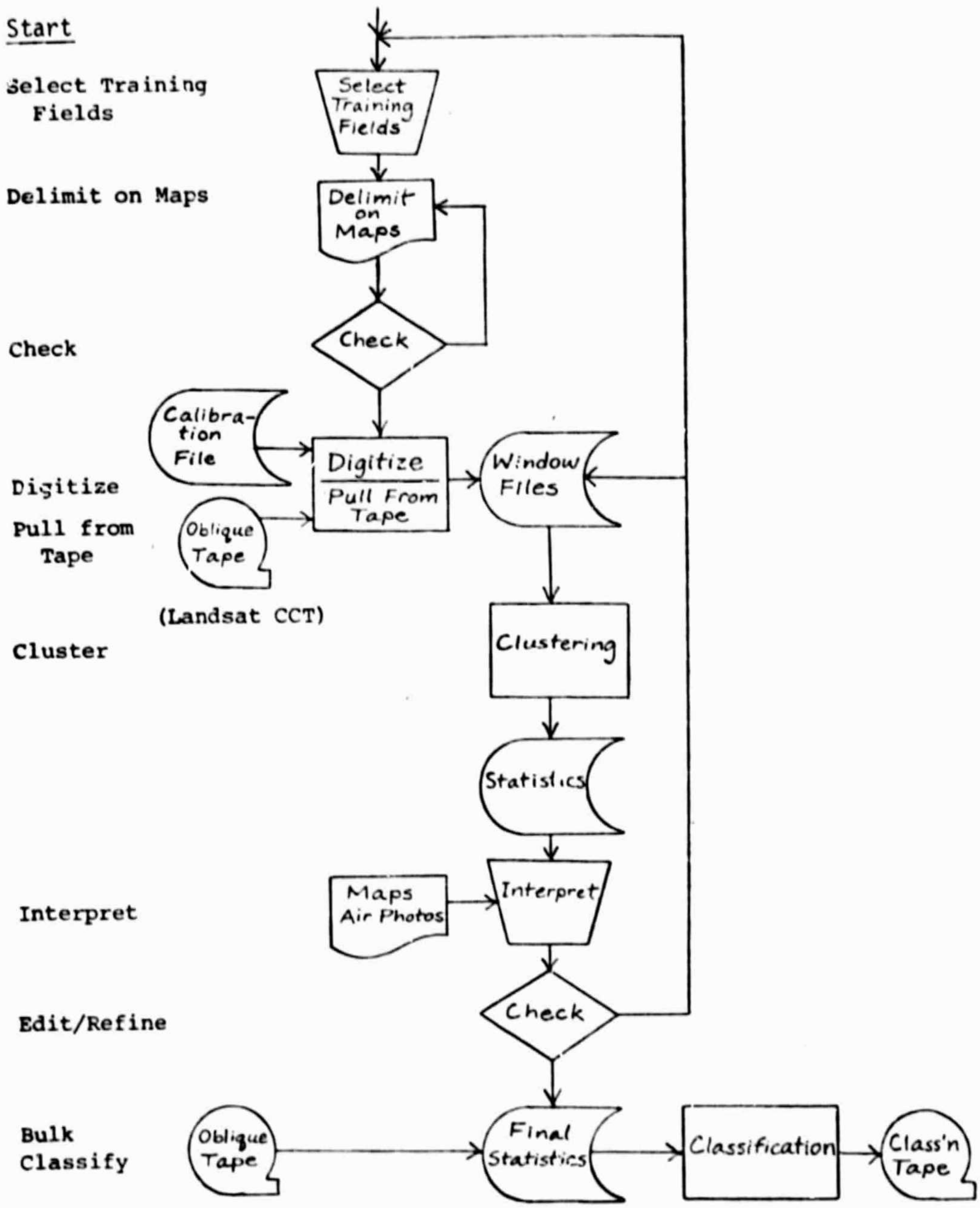


Figure 2.2-2 **Schematic of Steps in Interactive Classification of Landsat Data Using the EDITOR Program**

**Source: Mr. Leonard Gaydos, U.S. Geological Survey, Geography Program, NASA Ames Research Center**

judged representative of the intended cover type. These "training fields" were then grouped into seven, general cover types that could be used for spectral clustering. The training fields in each group were digitized from the USGS maps using an audio-type, spark-pen digitizer. The digitizing was done on-line, so that pixel data corresponding to the training fields was automatically pulled from the calibration file containing Landsat data for the study area and placed in "window files" corresponding to each training field/cover-type group.

Program commands could now be used to perform clustering on the pixel data within a window file. Any requested number of clusters could be established, with maximum possible separation achieved for that number. Typically, the number of clusters requested would equal, or be somewhat greater than the number of subclasses of land cover desired for that cover-type group. For example, seven clusters were requested in the case of the residential window file. The program provided statistics on the clusters established for each window file, which included the mean values and variances of the pixel data for each cluster with respect to each spectral band, and a matrix of distance measures between each pair of clusters. These statistics could be used to plot two-dimensional graphs of cluster locations and sizes (e.g., for Band 5 vs. Band 7, or other band pairs), to determine whether clusters intersected

or were cleanly separated. It was also possible to print categorized training fields on the lineprinter terminal, using number symbols to indicate the cluster assignment of each pixel. These categorized fields could be compared with the ground-truth training data or U-2 photography to determine the informational significance of the clusters, i.e., whether they represented meaningful distinctions in land cover that could provide a basis for subclassification of the general cover type. Reclustering to a larger or smaller number of clusters was done until the cluster set appeared to represent distinquishable and meaningful subclasses that could be named.

This routine was followed for each of the seven window files corresponding to cover type groups, until approximately 50 spectral clusters had been established. These were combined into one file, separations were computed, and their locations plotted. At this point, numerous incidences of cluster overlap appeared, and it was necessary to undertake a lengthy process of cluster elimination, combination, and re-position. In a few cases, new clustering of modified training data was done. Examples of difficult land cover discriminations involving overlapping clusters included tidelands, sedimented water, and wet, bare soil versus commercial/industrial and pavement classes, and wooded residential versus conifer and wetland classes. A first-version classification based on 40 clusters was produced after a five-week working period (about 12 man-weeks), however, this refinement was continued through several subsequent

versions by the USGS staff.

One remaining problem was that the classification broke down in mountainous areas that differed environmentally from the lowland areas used for training. Barren rock and seasonal melting of snow resembled some pixels in the urban and agricultural classes in the lowlands. This was corrected in the final version by stratifying the study area into upland and lowland zones. A digitized boundary was used to create a mask file in EDITOR that distinquished the pixels in the two zones. Then pixels in the problem area erroneously assigned to one class were reassigned to another using the IBM 360/67.

An experiment was also conducted in using Landsat data from two dates as a basis for producing a single classification, i.e., performing clustering on eight channels of data instead of four. The rationale was that seasonal differences could be exploited to produce cover discriminations not possible at one point in time. For example, four-band clusters representing agricultural fields that in June were bare and wet conflicted with pavement classes. The fields should be distinquishable from pavement when represented by eight band clusters incorporating additional data from August, when those same fields contained crops. This approach had been used successfully elsewhere over limited areas. However, for so large and diverse an area as the Puget Sound urban test site, it introduced complications that could not be dealt with in the demonstration.

The final version of the 1974 classification was based on 37 clusters or spectral classes, each identified as one of 14 named cover classes, as shown in Table 2.2-3. A number of products were distributed to the agencies, including lineprinter (LP) maps showing all the spectral classes, the named cover classes, other groupings, and Dicomed color-coded maps showing the 14 cover classes. The Dicomed maps were produced by color print enlargements from film negatives, and could be provided at any size for any part of the study area. An improved color print product of the entire test site was produced using an Optronics laser film recorder at the Jet Propulsion Laboratory (JPL) in Pasadena, California. This product was precisely registered to the UTM projection of the newly released 1:100,000 USGS county base map series for the Puget Sound region, and could be used as an underlay to transparent separations of those maps.

A second phase of product production involved the digitization of boundary sets for each agency's jurisdiction, and in some cases for districts and subareas within jurisdictions, to permit the tabulation of area summaries for land cover classes. Examples of these district geographic units included counties, cities, community planning areas, census tracts, and watershed units. Along with other manipulation and regrouping of the classified data, this work was performed with the "hands-on" participation of personnel from several of the user agencies. The ESL IDIMS (Interactive Digital Image Manipulation System)

Table 2.2-3

1974 Puget Sound Landsat Land Cover Classification

1974 Puget Sound Groupings for Final Products

| Land Cover | Spectral Classes (1-37) | LP Map Symbol | Dicomed Color* |
|---|---|---|---|
| Residential | 8, 29, 34, 35 | R | Blue |
| Mobile Homes | 17 | M | Pale Blue |
| Commercial/Industrial/Pavement | 3, 6, 15, 36 | C | Red |
| Cropland | 9, 19, 24, 25, 27 | + | Light Orange |
| Grass/Pasture | 10, 12 | ^ | Yellow |
| Deciduous | 11 | D | Lime |
| Regrowth Conifer | 31 | L | Turquoise |
| 2nd Growth Conifer | 5, 7, 13, 14, 30 | E | Dark Green |
| Old Growth Conifer | 4 | E | Olive |
| Water | 1, 2, 28 | 1 | Light Gray |
| Wetland | 23, 32, 33 | 3 | Medium Gray |
| Barren Land | 22, 26 | B | Orange Tan |
| Quarries | 16, 18 | V | Pink |
| Snow | 20, 21 | S | White |
| Border | 37 | | Black |

*From a list of 32 colors

at Ames, with its color display capability, was used for this spectral class regrouping and area aggregation by desired districts.

In late 1976, a new classification effort was undertaken by NASA and USGS using data from a Landsat-2 scene obtained on July 23, 1975 (2182-18201). Data analysis was performed by Mr. Willard Newland of USGS. The objective was to produce a new classification similar and comparable to the 1974 classification, to test the replicability of the methods and to investigate the potential for change detection. However, it was found impossible to exactly replicate the set of spectral clusters derived for the 1974 data. Spectral responses of each cover type were slightly different. Also, the new classification incorporated refinements in the processes of guided clustering, cluster editing, reclustering and stratification that led to a somewhat different result. The 1975 classes are shown in Table 2.2-4, which may be compared with the 1974 classes in Table 2.2-3.

As with the 1974 classification, 1975 lineprinter and color-coded Dicomed map products were prepared for agency use. Instead of a photographic color print enlargement of the entire test site, it was decided to produce a color lithograph product that could be reproduced in large quantity. The UTM-registered classification tape was sent to Seiscom Delta, Inc., Digital Images Division in Houston for production of color

Table 2.2-4

1975 Puget Sound Land Cover Classification

1975 Puget Sound Groupings for Final Products

| Land Cover | Spectral Classes (1-52) | LP Map Symbol | Dicomed Color |
|---|---|---|---|
| Residential | 9, 15, 16, 18 | R | Dark Blue |
| Wooded Residential | 19, 35 | R | Light Blue |
| Mobile Homes | 30 | M | Turquoise |
| Commercial/Industrial | 4, 8, 12, 17, 23, 25, 38, 43, 44 | C | Red |
| Pavement | 13, 41, 42 | P | Magenta |
| Cropland | 29, 31, 33, 34 | A | Pale Yellow |
| Grass/Pasture | 24, 28, 32, 52 | G | Cream |
| Brush/Shrub | 20 | + | Sand |
| Deciduous | 22, 26 | F | Pale Green |
| Mixed Forest | 14, 21 | F | Light Green |
| Regrowth | 48 | % | Yellow Green |
| 2nd Growth Conifer | 10, 11 | F | Olive |
| Old Growth Conifer | 36, 37 | F | Dark Green |
| Water | 1, 2, 6 | . | Light Gray |
| Turbid Water | 3 | . | Medium Gray |
| Wetland | 7, 27 | W | Dark Brown |
| Barren | 5, 39, 46, 49 | B | Light Brown |
| Ice/Glacial Debris | 50 | S | Dark Gray |
| Snow | 40 | S | White |
| Shadow | 51 | * | Black |

separations and a printed display map at a scale of 1:250,000. The color-coding was similar to that used in the Dicomeds. This product saw wide distribution within and outside of the project user community, and was an important information vehicle for both the Puget Sound Urban Demonstration and the LRIDP.

A list of the minimum set of output products from both the 1974 and 1975 classifications furnished to a participating county agency is shown in Table 2.2-5. In addition, there were unique deliverable products with area windows, scales, class groupings, district overlays and tabular summaries to specifications requested by individual agencies.

The USGS staff at Ames briefly attempted a comparison of the 1974 and 1975 classifications for change that may have occurred between the two dates. In a few instances changes involving sizable areas of land such as new clear cuts and large residential subdivisions were detected and correctly identified. However, the general conclusion reached was that most of the differences in pixel classification between the two products were spurious, i.e., due to factors other than actual land cover change. Among these were a slight seasonal difference (June/July), a difference in conditions between the two years (1974 a wet year, 1975 dry), and the differences in spectral clustering and grouping. These factors constituted a type of "noise" that for the most part overwhelmed the very small amount of actual change that

**Table 2.2-5**

**Output Products from the 1974 and 1975 Puget Sound Land Cover Classifications Furnished to User Agency Participants**

LP Maps, every class, full frame
LP Maps, every class, county
LP Maps, grouped classes, full frame
LP Maps, grouped classes, county
Dicomed Transparency, full frame
Dicomed Transparency, county
Dicomed Negative, full frame
Dicomed Negative, county
Color Print, no specific scale, 8 X 10, full frame
Color Print, no specific scale, 8 X 10, county
Color Print, no specific scale, 11 X 14, full frame
Color Print, no specific scale, 11 X 14, county
Color Print, 1:100,000, county-minimum enclosing rectangle
Color Print, 1:500,000, full frame
Color Print, 1:250,000, full frame
Printed Map, 1:250,000, partial frame
Color Slide, full frame
Color Slide, county
Classification Tape
Land Cover Totals, county
Cluster Ellipses Chart
Color Key Chart

occurred in the short time period of one year.

Most of the project participants had high expectations for a capability to monitor change, and regarded this as one of the major, potential payoffs of Landsat — particularly if repeat classifications of the same geographic area could be accomplished at substantially reduced cost by utilizing the same digitized training fields, district boundaries, and map transforms, and capitalizing on accumulated experience.

The desirability of attempting one classification, based on one large set of training data for such a large area, versus individual classification of smaller areas using locally representative training data, was debated throughout the project. One indication of the validity of the large-area approach was provided by a final experiment conducted by the Ames USGS investigators in which the 1974 classification statistics for the Puget Sound test area were first applied to the entire Central Puget Sound Landsat scene, and then to the contiguous, same-date scenes to the north and south, for a total of three scenes extending from Vancouver, B.C. to Portland, Oregon. The classification of the southern scene was compared with a LARSYS classification of a much smaller area developed by the LRIDP Portland Urban Group, and was found to yield very similar results.* Considering that the labor involved in

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* Leonard Gaydos, "Low-Cost Computer Classification of Land Cover in the Portland Area, Oregon, by signature Extension Techniques," Journal of Research, U.S. Geological Survey, Vol. 6., No. 6, Nov.-Dec. 1978, P. 815-819.

in producing the EDITOR classification for three scenes (100,000 sq. km.) was only a few times that required to classify metropolitan Portland alone (1,500 sq. km.), this "signature extension" technique holds promise for cost-effectiveness. Unfortunately, it is limited to situations of contiguous, same-day coverage along one Landsat path.

### 2.2.2 Project Evaluation

From a technical standpoint, the LRIDP Puget Sound Urban Demonstration was a success in the fact of its completion. A comprehensive categorization of land cover in one of the most diverse regions, over a geographic area that ultimately extended to three scenes, was unprecedented in Landsat applications prior to 1976. The attempt to address the needs of a large and varied community of local government and other users through one basic data analysis was also unique. The communication and interaction among user agencies, the University of Washington, the PNRC and the sponsoring Federal agencies was beneficial in ways that extended beyond the project both in time and problem context. The exchange of ideas about common concerns in the use of data for land planning was a value recognized both for this project and the LRIDP as a whole. This dialogue was encouraged by frequent participant contact in project meetings, training, analysis sessions at Ames, and the major urban discipline reviews in July 1975, October 1976, and October 1977 that also permitted exchange with the LRIDP urban projects in Spokane,

Portland, and Boise. Much of the user evaluation that occurred was communicated during these reviews.

From an application and technology transfer standpoint specific to first-generation Landsat technology, the results of the Puget Sound Urban Demonstration were less conclusive. Initial reactions of users were mixed and sometimes contradictory. Most were clearly awed by technological sophistication involved in creating the data products, which were widely exhibited by the users to management in their agencies and to their public constituents However, uncertainty about how to use the products for other than pictorial purposes was common at first.

Many users tried to relate the lineprinter output to other mapped information on a USGS 7 1/2' base, but were concerned about uncertainty in positioning individual pixels and locating them on the ground. Comparisons were made with other data and many isolated instances of location or classification disagreement discovered. These disagreements were usually reported as "error" in the Landsat data, the comparative data being regarded as "truth" in these cases, sometimes without considering its source or age, or differences in the way information categories were defined. Agencies were provided with a set of the September 1975 U-2 photography and encouraged to use this medium for Landsat product verification. No consistent method of accuracy definition and determination was suggested or followed. Several agencies reported accuracy figures of 70-80% for their

jurisdictions. Some agencies stated acceptance criteria that were higher than this — 85-90%. Gradually the realization was gained that the Landsat land cover classification presented a different though not necessarily less valid description than that provided by conventional land use information.

User interest and satisfaction rose in the later phases of product development. Many of the obvious classification errors in the early versions of the 1974 classification were corrected in the final, stratified version. Further improvement was noted in the 1975 classification products. Also, for the first time, many participants had an opportunity to visit NASA-Ames for "hand-on" experience, using the ESL IDIMS interactive display system to manipulate the classified data and produce spectral class groupings and area summaries to suit their particular needs. These summaries of land cover class acreages for planning areas, districts, and other geographic units commonly used for land use area tabulation yielded results that compared much more closely with conventional data, and thus avoided concern over individual, misclassified pixels.

The LRIDP Phase IV User Needs Study conducted during the latter part of the Puget Sound Demonstration (October 1976-October 1977) provided an opportunity for agencies to focus their thinking on potential applications.* Most agencies saw a basic area of

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* Frank V. Westerlund and Donald E. Wilson, Final Report, Phase IV User Needs Study, Pacific Northwest Regional Commission Land Resources Inventory Demonstration Project, NASA Ames University Consortium Interchange Agreement NCA 2-OR850-701, November 1977.

application in comprehensive planning. Map products and tabular summaries portraying existing land use and undeveloped land resources could facilitate the process of policy/plan analysis, formulation, review, and update, a process which most of the local governments conducted on rotating schedule for community planning areas. The value of the Landsat data products for both data development by planning staff and for public communication in meetings with decision-makers and the public was recognized by most participants. This was the major use made of the project products.

A second application forseen by most agencies was the incorporation of Landsat data into jurisdiction-wide land use data bases, for purposes of data base upkeep and monitoring change. This was usually viewed as a problem of updating files in whatever form they existed, such as land use files keyed to assessor's or other administrative records and maintained on file cards, maps, or in a computerized system. The complexities involved in relating Landsat data to parcel-level data, particularly in an urban context, were frustrating to some users and could not be dealt with in the demonstration. The City of Tacoma, which was developing its Land Use Management Information System (LUMIS) for interactive graphic display of multiple data files, was the only participant that moved in this direction.

Predominantly rural jurisdictions such as Mason and Jefferson counties either lacked a parcel data base or found such existing data of little use in planning because of the large size of most ownerships. For them, Landsat represented an opportunity to acquire an areawide land data base for the first time, and there was less concern about accuracy or compatibility with existing data.

A few large agencies, PSCOG, Snohomish County, and King County were considering development of computerized land information system incorporating units larger than parcels, such as grid cell land divisions or census tracts. Where these units are large enough for meaningful area summary by constituent land cover classes, they present a realistic option for Landsat data integration. Small grid units such as the 10-acre cell system of Snohomish County and a 5.75-acre cell system contemplated by PSCOG presented technical problems of registration and classification assignment that were not resolved and diverted much effort and attention away from attainable objectives of the project. Quarter-sections (now employed by King County) would have been a practicable cell unit for Landsat/data base integration using an area summary approach.

Integration of the 1975 land cover classification with census data using 1970 census tracts in King County was accomplished in a separate project at the Jet Propulsion Laboratory, for the U.S. Bureau of the Census.* JPL's VICAR/IBIS software system was

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* Steven Z. Friedman. MAPPING URBANIZED AREA EXPANSIONS THROUGH DIGITAL IMAGE PROCESSING OF LANDSAT AND CONVENTIONAL DATA. JPL Publication 79-113 Jet Propulsion Laboratory, California Institute of Technology PASADENA, CALIFORNIA. MARCH 1, 1980.

used. The value of this approach for data base development was recognized by the Puget Sound agencies participating in the subsequent Landsat Application Program (LAP) VICAR/IBIS Demonstration Project (section 2.3). Landsat/census data integration also provided a direction for future work, when possibilities for file update and change detection could be given an adequate test.

Other applications identified in the User Needs Study were in specialized areas such as transportation planning, growth forecasting, shoreline management, EPA 208 water quality planning, flood plain delineation, agricultural land preservation, and site suitability for gravel extraction and solid waste disposal. Some of these involved input to analytical models, such as PSCOG's Activity Allocation Model (growth forecasting), transportation. models, and watershed runoff models for 208 planning. The value of land cover data summaries for the specific geographic units employed in these models was apparent. Actual data use in such analysis during the project was limited. The City of Tacoma used Landsat-derived acreage of residential land cover in studies of population density for its planning areas. Land cover data was summarized by watershed units in Snohomish County for use in 208 planning.

It was the consensus of most participants that the Puget Sound Urban Demonstration Project was effective as a first step in technology transfer. It achieved an awareness throughout the Puget Sound region of satellite remote sensing technology and

its potential applications in local government. A number of agency personnel acquired the knowledge to apply Landsat product data to real problems, and a few attained competence in Landsat data analysis. It should be realized also that for most participants the project was an introduction not only to Landsat but to the entire applied science of remote sensing. Exposure to basic remote sensing theory and related concepts in cartography and geographic information system was important. Use of the supporting U-2 photography was a significant element of project work by agency personnel, and was helpful in elevating users first to "U-2 scale" analysis before continuing to "Landsat scale." Skills developed in photointerpretation of small scale imagery, both U-2 and Landsat, may yield future benefit when second-generation satellite imagery (Landsat-D Thematic Mapper, SPOT, etc.) with resolution of urban detail becomes available.

It was apparent that the technology transfer process had to continue and that a technical and institutional base for its support had to be established in the region. This was the objective of the Landsat Applications Program (LAP) in which an operational Landsat data analysis capability was established in Washington State (sections 2.1.2, 2.3).

## 2.3 The LAP VICAR/IBIS Demonstration Project (UW-RSAL), 1979

### 2.3.1 Objectives

In this project, UW-RSAL was funded by PNRC under the Landsat Application Program to demonstrate usage of the VICAR/IBIS

software system to agencies in the Puget Sound region. The primary objective was to assemble Landsat data, the existing land cover classifications (1974 and 1975), digitized map data and related files on the WSUCSC Amdahl computer system for use by state and local planning agencies. The study area focused on central Puget Sound, but through use of data from the 1974 three-scene, signature-extension classification, it was possible to address interests of agencies in other parts of western Washington.

A major emphasis of the project was showing participating agencies how to access the data bank, software and hardware from a remote terminal and to receive output from a remote job entry (RJE) station, using the terminal located in RSAL and the RJE station located in the UW Urban Data Center.

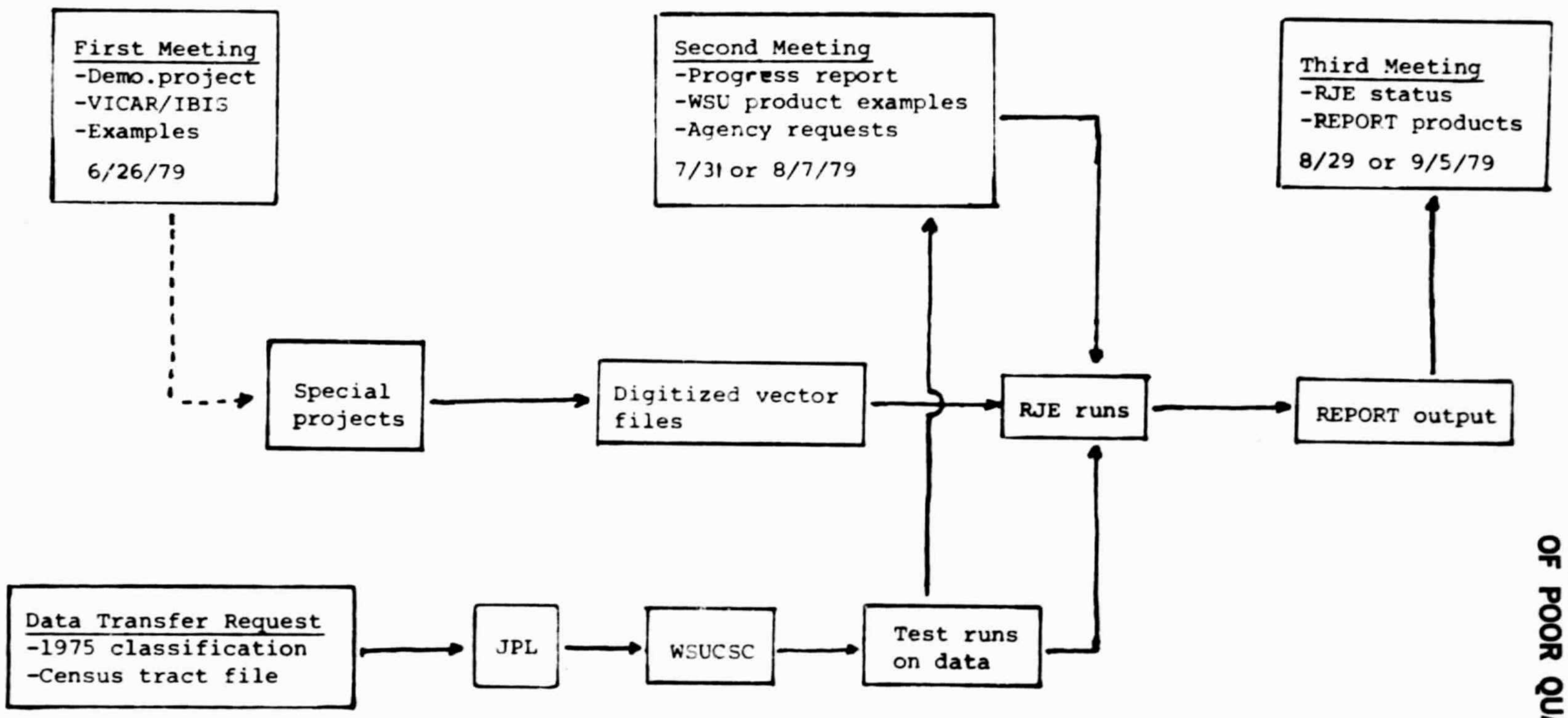
A flow chart indicating the relationship of components of the demonstration is shown in Fig. 2.3-1.

### 2.3.2 Participation

Twenty-nine persons representing 14 local and state agencies and two other units of the University of Washington participated in the demonstration. These are listed in Appendix B. In order to accumulate the required 50/50 match of PNRC and agency resources on the contract with PNRC, agency staff time and travel were documented.

Figure 2.3-1

VICAR/IBIS DEMONSTRATION



### 2.3.3 Training of UW-RSAL Investigators and Agency Personnel

The co-investigators were trained by staff at the Jet Propulsion Laboratory (JPL) in Pasadena, California in May, 1979. Additional training in the WYLBUR file management software system was given by WSUCSC at Pullman and Puyallup.

### 2.3.4 Selection and Use of a Common Set of Land Cover Data

All previous Landsat products for Puget Sound were transferred in digital form to WSUCSC to start a library of Landsat data tapes. This included raw data tapes and classified data for 1974 and 1975, and image formatted census tract boundaries from JPL.

The basic data set selected was the 1975 spectral classification of the Puget Sound scene developed by Gaydos and Newland of the USGS Geography Program at NASA-Ames. The 52 spectral classes in this data set may be associated according to information needs of the individual user. Some agencies were interested in inventorying vacant land, other grassland, impervious surfaces and agricultural lands. Some wished to tabulate general land cover cover associations by census tract. All were attempting to find information to corroborate other surveys they had made, and seeking more accurate and economical methods. DISPLAY was the VICAR/IBIS routine used for output.

### 2.3.5 Verification of Results

Western Washington University participated in the demonstration and opened an account. Files were obtained for the 1974 Landsat of classification of the scene north of Puget Sound. The WWU efforts have involved agencies in that vicinity and have extended the potential use of VICAR/IBIS.

Two consulting firms used the data files to complete contractual work with local government. Also, San Juan County opened an account for the purpose of establishing a land use information system (section 2.4.4). A UW graduate student has used VICAR/IBIS and a 1978 data tape for Puget Sound to explore means of updating the Coastal Zone Atlas of Washington.

Appendix C. lists VICAR/IBIS jobs requested by the project participants.

The agencies were unanimous in their expressed needs for a 1980 land cover classification and the 1980 census tract boundaries overlay. The computation of population densities and their patterns of distribution in the local jurisdictions were the immediate information latent in Landsat/census data integration by VICAR/IBIS.

## 2.4 Multi-Purpose Applications of Puget Sound Classified Landsat Data

Several applications were made of the 1974 and 1975 spectral classifications/land cover associations that were at least partly independent of the LRIDP Puget Sound Urban Discipline Project and the LAP VICAR/IBIS demonstration, although they

included two other application activities funded under LAP.

### 2.4.1 UW-RSAL/U.S. Air Force Project, 1977-78

In April 1977, UW-RSAL contracted with the U.S. Air Force Environics Laboratory at Tyndall AFB, Florida, to conduct a study of remote sensing methods for land use inventory in the vicinity of Air Force Bases. Under its Air Installation Compatible Use Zone (AICUZ) environmental planning program, the Air Force has established standards for noise, air pollution, and accident hazard impacts around its bases. These standards are specific to identified land uses. The Air Force was was interested in a cost-effective method of acquiring its own land use data for the environs of its facilities, data that would be consistent with its impact analysis methods and independent of data collection by local communities. Of special interest was a method of quickly updating such data each time that a "mission realignment," (i.e., a change in operations) produced new patterns of noise and other impacts.

The UW-RSAL study compared three techniques: (1) photointerpretation of high-altitude aircraft imagery. (2) equidensitometric processing of both aircraft and Landsat imagery and (3) digital classification of Landsat data. Two test sites were used, McChord AFB near Tacoma and Fairchild AFB near Spokane. The 1975 Puget Sound spectral/land cover classification was utilized for the McChord Landsat digital product, in the form of 1:24,000 lineprinter output showing all spectral classes and

a specified grouping into land use/cover classes with symbols chosen for maximum legibility of homogeneous units. Polygons defining homogeneous land use/cover were outlined on the line-printer maps, which were then overlaid with Air Force-supplied maps showing Ldn (Level, day/night) noise contours. Areas of each land use/cover class within each noise contour interval were measured using the RSAL Numonics 1224 planimeter/digitizer. Tabular summaries of this data provided the required quantification of noise impact. The Fairchild AFB digital product was produced as a new classification as part of the EDITOR remote access demonstration (Section 2.1.4). In this case, noise contour data was digitized from the Air Force maps using the Numonics 1224 and a transmission was attempted via the WATS telephone line for incorporation as a digital mask in EDITOR. The telephone technique was not appropriate for digitizing. File transfer was necessary as a final solution with assistance provided by Ames Research Center.

### 2.4.2 City of Tacoma LAP Project, 1978-79

In this effort, the City of Tacoma completed the installation of interactive data management software on the city's computer system, allowing it to store and access land cover data from the 1974/1975 Landsat classifications, in combination with other files including census DIME files, street and engineering data, and other physical and statistical data parameters.

### 2.4.3 Washington Department of Game, Mount Vernon Office, Grouse Habitat LAP Project, 1978-79

In 1978, Washington State Game Department biologist Mr. Larry Brewer contracted UW-RSAL for advice on vegetation data useful in a study of ruffed grouse habitat in western Washington, in particular, lowland timbered areas. It was suggested that the 1974 three-scene Landsat classification of western Washington might provide a suitable land cover data base that could be analyzed to produce required habitat acreage information. PNRC and NASA-Ames were contacted and support obtained for a LAP application activity.

Brewer and James Eby of RSAL traveled to NASA-Ames in late 1978 to access the 1974 Landsat classification, which was displayed in color on the ESL IDIMS system. Spectral classes were checked in areas where ground cover data had been collected in Game Department grouse census field work. Of the total of 37 spectral clusters, 10 were identified as representing forest land cover types and were ground grouped in six categories as a breakdown for acreage calculations. Those spectral clusters not representing forested land were grouped into nine general land cover classes that were included in the map products.

The next task undertaken at Ames was to combine a study boundary (all of western Washington below 2,000 feet elevation) and the county boundaries with the Landsat classification. These

boundaries had been delineated on a 1:500,000 scale map, and were digitized on an Altec digitizer coupled to a terminal that accessed EDITOR software on computers at Ames and at Bolt, Baranek and Newman in Boston, via ARPANET. The digitizing process produced a computer file of line segments, which were checked for accuracy on a CRT plotter. An EDITOR routine generated a mask from the line segment file which was used to divide the Landsat land cover data into areas below or above 2,000 feet, by county. Tabular summaries were prepared showing acreage of each of the six forest land cover types, below and above 2,000 feet elevation for each county. This tabulation is shown in Table 2.4-1.

Existing vegetation maps of the Skookumchuck River drainage and low-altitude color aerial photos of the Nooksack River Drainage were used to make a numerical evaluation of the accuracy of the Landsat classification. A sample of 52 10-acre test plots (including 468 Landsat pixels) showed a 5-8% error, based on the number of pixels that did not display the ground cover indicated by the other sources. This was regarded as a very high correlation with these forms of ground truth.

The three-scene Landsat classification did not include the western parts of the counties on the Washington seacoast. The USGS Land Use and Land Cover Map Series (dates 1973-1975) were used to obtain most of the missing data. Clear-cut and regrowth areas were added to these maps by manual photo interpretation

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Table 2.4-1

Acres of Forest in Counties of Western Washington Above and Below 2,000 Feet Elevation

| County | | Old Growth Conifer* | 2nd Growth Conifer | Deciduous Forest | Conifer Deciduous Forest | Barren Clear-cut | Clear-cut Regrowth | Total |
|---|---|---|---|---|---|---|---|---|
| Whatcom | + | 122,662 | 115,371 | 1,366 | 3,236 | 17,808 | 74,433 | 334,876 |
| | - | 32,098 | 122,244 | 111,563 | 56,189 | 6,571 | 33,235 | 361,900 |
| San Juan | + | — | — | — | — | — | — | — |
| | - | 4,304 | 57,952 | 9,297 | 11,108 | 872 | 11,142 | 94,675 |
| Skagit | + | 104,250 | 109,063 | 12,147 | 4,706 | 14,929 | 60,575 | 295,670 |
| | - | 38,067 | 171,097 | 107,523 | 70,057 | 4,262 | 30,563 | 421,569 |
| Snohomish | + | 116,032 | 83,783 | 1,174 | 2,183 | 14,080 | 54,739 | 271,991 |
| | - | 72,723 | 233,969 | 152,909 | 112,949 | 9,132 | 52,240 | 633,922 |
| Island | + | — | — | — | — | — | — | — |
| | - | 918 | 41,925 | 23,680 | 23,572 | 1,395 | 12,817 | 104,307 |
| King | + | 108,160 | 104,656 | 1,174 | 4,072 | 18,308 | 51,277 | 287,647 |
| | - | 40,231 | 254,961 | 147,852 | 117,691 | 14,252 | 73,820 | 648,807 |
| Kitsap | + | — | — | — | — | — | — | — |
| | - | 2,480 | 106,508 | 43,447 | 43,909 | 2,219 | 25,535 | 224,098 |
| Mason | + | 13,818 | 28,139 | [illegible]64 | 911 | 2,185 | 12,955 | 58,272 |
| | - | 22,088 | 258,542 | 67,45[illegible] | 71,398 | 7,437 | 66,068 | 492,984 |
| Pierce | + | 93,080 | 118,384 | 2,306 | 9,951 | 17,615 | 35,883 | 277,219 |
| | - | 12,324 | 222,856 | 78,892 | 93,513 | 18,057 | 66,580 | 492,222 |
| Thurston | + | 29 | 1,567 | 86 | 328 | — | 30 | 2,040 |
| | - | 4,299 | 127,769 | 107,668 | 86,946 | 5,423 | 52,007 | 384,112 |
| Lewis | + | 94,636 | 130,689 | 5,787 | 10,658 | 11,315 | 46,753 | 299,838 |
| | - | 36,794 | 234,916 | 263,675 | 160,367 | 11,309 | 106,175 | 813,236 |
| Cowlitz | + | 32,948 | 38,365 | 2,094 | 5,252 | 9,807 | 30,760 | 119,226 |
| | - | 54,234 | 183,779 | 121,054 | 85,834 | 9,984 | 68,242 | 524,127 |
| Clark | + | 3,312 | 7,729 | 1,310 | 1,739 | 140 | 2,711 | 16,941 |
| | - | 10,780 | 79,955 | 75,145 | 46,058 | 4,176 | 44,686 | 260,800 |
| Skamania | + | 119,130 | 96,086 | 2,834 | 3,605 | 13,373 | 51,659 | 286,687 |
| | - | 38,431 | 48,221 | 14,958 | 11,500 | 3,055 | 15,829 | 131,994 |
| Wahkiakum | + | — | — | — | — | — | — | — |
| | - | 2,444 | 49,441 | 25,793 | 17,675 | 1,723 | 23,345 | 120,421 |
| Pacific | + | — | — | — | — | — | — | — |
| | - | 7,571 | 205,201 | 85,338 | 122,497 | 21,792 | 76,999 | 519,398 |
| Grays Harbor | + | 5,730 | 14,814 | 293 | 351 | 1,336 | 7,177 | 30,701 |
| | - | 26,897 | 544,685 | 174,716 | 153,832 | 32,538 | 156,112 | 1,088,830 |
| Jefferson | + | 45,397 | 93,486 | 499 | 2,490 | 5,188 | 38,139 | 187,199 |
| | - | 28,082 | 408,433 | 52,109 | 43,946 | 36,676 | 69,761 | 639,007 |
| Clallam | + | 29,225 | 72,693 | 213 | 1,848 | 3,386 | 11,601 | 118,966 |
| | - | 15,231 | 612,820 | 26,271 | 32,375 | 27,295 | 77,722 | 791,714 |
| TOTALS | + | 889,409 | 1,016,825 | 21,547 | 51,330 | 129,470 | 478,692 | 2,587,273 |
| | - | 449,996 | 5,965,274 | 1,689,341 | 1,361,416 | 218,218 | 1,063,878 | 8,748,123 |
| | | | | | | GRAND TOTAL | | 11,335,396 |

*Conifers 135 years or older.

Source: Larry W. Brewer, The Ruffed Grouse in Western Washington, Washington State Department of Game, Biological Bulletin No. 16, May 1980.

on the RSAL Bausch and Lomb Zoom Transfer Scope. Complete air photointerpretation was done for a small area in Pacific and Grays Harbor counties covered by neither the Landsat classification nor the USGS Land Use/Cover Maps. Field checks of the photo-interpreted areas were carried out along a preplanned route including 35 sites. Land cover data from these sources was compiled on a 1:250,000 scale base map and acreages calculated using the RSAL Numonics 1224 electronic planimeter. These acreages were then added to the Landsat totals.

The final use of this information was to provide total spring and fall population estimates for ruffed grouse. Timber acreage from the Landsat analysis was combined with grouse density estimates from audio census counts in the following equation for estimating spring population:

$$Ps = \frac{A}{B}$$

Ps = Spring Population

A = Acres of lowland timber in western Washington

D = Grouse density in acres per bird

The fall population was calculated as a function of spring population, incorporating a factor for August brood size.

The Grouse Habitat Study is an outstanding example of how classified Landsat data, prepared for one set of purposes, can be applied to wholly different problem in another discipline, when the data is available as a set of original spectral clusters

that can be combined in a new grouping to satisfy specific needs. The power of this analytical approach lies in the universality of a set of classified spectral information representing one point in time, for a large but integral region such as Puget Sound — i.e., a well-defined region with characteristic natural systems and human settlement patterns that are fairly consistent throughout.

### 2.4.4 San Juan County 1979

In 1979, San Juan County, Washington opened a computer account at WSUCSC for purposes of establishing a land information system incorporating Landsat spectral/land cover classifications. Line-printer map products from the 1974 three-scene classification were provided for evaluation by county planners.

The diversity of uses of the 1974/1975 Landsat classifications that had occurred by 1979 indicated the operational philosophy that was then adopted for the LAP VICAR/IBIS Demonstration and the follow-on UW-RSAL/NASA-Ames Interchange, that of establishing a widely accessible file of regional, Landsat-derived spectral/land cover data and related map and statistical data, and maintaining and updating these files on a continuing basis.

## 2.5 1980 Land Cover Project

By 1980, several factors argued for the development of a new Landsat digital land cover classification of the Puget Sound

region comparable to the 1974-1975 classifications produced in the LRIDP Puget Sound Urban Demonstration Project. These factors included the following:

1. Land development had been active in the Puget Sound region during the period 1976-1979. The five-year interval that would separate the 1975 classification and a 1980 classification would include this growth and offer a reasonable opportunity for assessing change detection capabilities of Landsat.
2. The U.S. Census of Population occurred in 1980 (nominal date: April 1, 1980). Classification of a Landsat scene approximating this date should permit comparison of land use conditions with demographic data from the census. Also, the 1980 Census incorporated new census tract boundaries in parts of the Seattle-Everett and Tacoma SMSA's. Agencies that had used the 1975 land cover data summarized by 1970 census tracts in the LAP VICAR/IBIS Demonstration needed to produce new summaries for the 1980 tracts and wanted contemporaneous land cover data for this purpose.
3. The State of Washington had acquired an operational Landsat data analysis system in the VICAR/IBIS installation at WSUCSC. The IBIS portion of the system had been exercised using the UW-RSAL terminal linked to the Urban Data Center RJE station for manipulation of the 1975 classified data and the 1970 census tract overlay in the

LAP VICAR/IBIS Demonstration. However, there w no experience in using VICAR for spectral classification in the Puget Sound environment. VICAR/IBIS differs in important respects from EDITOR. VICAR/IBIS is a batch system. EDITOR is more interactive. VICAR/IBIS incorporates a parallel piped classifier in FASTCLAS, compared to EDITOR's maximum likelihood classifier. A VICAR/IBIS classification of the Puget Sound region that attempted to replicate as closely as possible the 1974-1975 EDITOR classification would be able to assess these differences and establish an operational approach to classification based on the state's image analysis system.

A 1980 Puget Sound land cover classification project was undertaken by the University of Washington, Remote Sensing Applications Laboratory through a University Consortium Interchange Agreement with NASA Ames Research Center. The project commenced on March 1, 1980 and was continued under a revised agreement from December 1, 1980 to September 30, 1981.

The project approach, as outlined in these agreements, included the following steps:

1. Acquisition by NASA of Landsat data meeting the following criteria: (1) cloud cover not exceeding 10%; (2) quality of individual bands not less than 5; (3) preceding and following scenes on the same orbit meeting the first two criteria; (4) a date as close as possible to the April 1,

1980 Census of Population; (5) color composite available or capable of generation; (6) early availability of data.

The data that most nearly met these criteria was a Landsat-2 scene of July 20, 1979 (1640-18140). This was deemed acceptable since it was within nine months of the census and there had been little development in the region since mid-1979.

2. Classification of a small area of the 1974 Landsat CCT using FASTCLAS, to familiarize the investigators with this VICAR routine while awaiting acquisition of the new data.

3. Documentation, for training purposes, of the practical aspects of using VICAR/IBIS routines for classification (a continuing task throughout the project).

4. A meeting of local and state agency users to secure their cooperation in the project and their assistance in identifying current land cover conditions in the training sites and in later checking of verification sample areas. A subsequent meeting was also contemplated to inform users about the public data files to be made accessible to them.

5. Classification of the selected 1979 Landsat data for the Puget Sound scene using VICAR routines, with all jobs submitted from the terminal at UW-RSAL. Dicomed prints and a color negative were requested to be provided by NASA Ames for checking intermediate progress.

6. Sampling of the final classification to allow 85% confidence in an accuracy determination over all classes. Use of a contingency table to test the classification against 12-pixel sample units photointerpreted from October 1980 U-2 photography (NASA-ARC Flight 81-003). Local agency field check of sample areas.

   A stratified sample by Level I classes was an option considered initially. This would have required preparation of software to sample pixels by their geographic coordinates. Instead, the random sample employed was based on a prior selection of the 12-pixel sample units using a random integer sampling routine applied to kilometer intersections in a UTM coordinate grid.

7. Data summarization by census tracts. As originally envisioned this consisted of four steps: (1) 1979 classification summarized by the 1970 census tracts; (2) 1980 census tracts obtained in digital form and registered to the USGS 1:100,000 base; (3) 1979 classification summarized by 1980 tracts; and (4) 1975 classification summarized by 1980 tracts and compared.

   These steps could not be completed within the funding constraints of the Consortium Agreement. At the time of this writing, the 1979 classification summary by 1980 tracts is in progress under funding from the King County

Department of Community Development.

8. Use of statistics for the 1979 land cover classification to clasify the preceding and following Landsat scenes in the same orbit.

   This also could not be completed under the Consortium Agreement. The preceding (northern) scene extending to Canada has been acquired and classified under an arrangement with the Washington Department of Game. The southern scene for this date is more than 20% cloud covered and is probably not suitable for classification.

9. Preparation by NASA-Ames of Dicomed color enlargements of the 1979 classification for the entire scene and for subareas.

10. Final report, including a history of events leading to the 1980 Puget Sound Land Cover project, starting with the LRIDP Puget Sound Urban Demonstration Project in 1975.

The remainder of this report is devoted to the 1980 Puget Sound Land Cover Project and documents the work done in producing and verifying the land cover classification based on 1979 Landsat data.

# 3.0 AN APPROACH TO MULTI-PURPOSE LAND COVER CLASSIFICATION WITH VICAR

## 3.1 Introduction

Use of the extensive spectral classification of a Landsat scene by more than one disciplinary interest is vital in the cooperative effort to reduce Landsat data processing costs. Some have concluded that it is futile to pursue such optimism but they tend to be those who can pay for doing it their own way.

### 3.1.1 Local Planning Agencies

Local planning agencies are not the typical big spenders in Landsat data processing. Their planning areas cover less than a Landsat scene, even if they are a large western U.S. county. Their staffs usually do not include a trained Landsat data analyst. Most have no specific budget for acquiring information from Landsat. They are a prime group for the sharing of costs in a multi-purpose land cover classification.

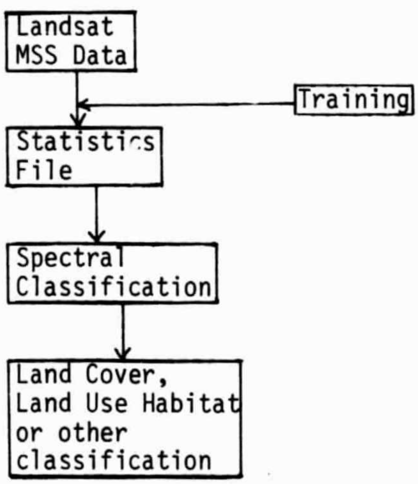
### 3.1.2 Basic Purpose

The basic process can be simply diagrammed as shown in Figure 1. Landsat multispectral scanner (MSS) data is currently four bands of reflectance for a single scene. Additional bands from other data or from the future Thematic Mapper can be accomodated in VICAR. The data has a range of values from 0 to 127 in each of the four bands. Spectral response of an object on the earth's surface is variable in each of these bands.

### 3.1.3 Spectral Signature

Spectral signatures are known spectral responses for specific land cover types. These signatures are represented by a set of means and covariances in each band. Spectral signatures are a variation of some land cover class in most cases.

Figure 3.1.3: Simple Process from Landsat to Land Cover




Training on variations of each land cover class is required. Several examples of the same variation of cover are used to derive a spectral signature representing that class. These examples are called training sites. Pixels that are contained in the training sites produce the desired statistics. The resulting statistics will be radiometrically true to the specific scene in which the training is done. Preceding or following scenes in the same orbit may be close enough to verify the results of classification.

### 3.1.4 Resolution

Spectral signatures are not just spectral responses of objects. A generalization of data occurs in the sensing by Landsat and also in the training step. The resolution or "instantaneous field of view" of the Landsat MSS is 79 meters. Current EDIPS processing results in square pixels of 57 meters. In the pixel, many objects are sending spectral responses which are mixed and recorded as one reflectance value by Landsat. See Figure 3.1.6 for a residential mix. The 57 meter pixel has a large number of objects, 53. The 30-meter resolution of the Thematic Mapper would reduce the number but not eliminate a mix of objects with different spectral response.

### 3.1.5 Training Sites

Training sites usually include several pixels, maybe 10. As many as five such locations are desired for the same signature to be based on a minimum of 50 pixels for the statistical set of means and covariances.

### 3.1.6 Myopic Approach

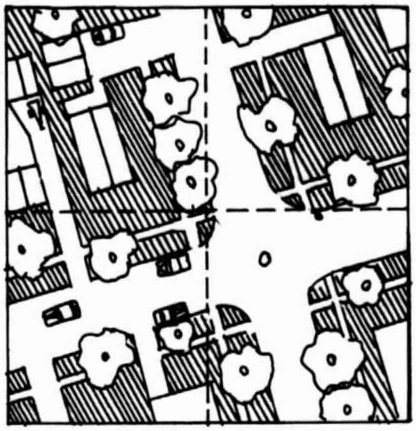
This approach is myopic in that each variation of a land cover type is represented by a spectral signature. Training is conducted for each signature to produce the statistical basis for a large set of spectral classes. Each spectral class is represented by a set of means and covariances in the statistics file used for classification of the data.

Figure 3.1.6: Objects in One Residential Pixel

Single Family
Residential
Tract Example

Approximate
Population
Density=
10,000 pop./sq.mi

Scale 1:1000



North

| Legend | 60 m Pixel | 30 m Pixel | Range |
|---|---|---|---|
| Trees | 17 | 4.25 | 4-5 |
| House and garages | 3 | .75 | 0-2 |
| Partial Bldgs | 6 | 1.50 | 1-3 |
| Sidewalks | 4 | 1.00 | 0-2 |
| Streets, driveways and patios | 10 | 2.50 | 2-4 |
| Vehicles | 5 | 1.25 | |
| Grass lawns | 8 | 2.00 | 1-4 |
| Total | 53 | 13.25 | |

3.1.7 Definition

The spectral signatures need to be recorded in all their descriptive detail to aid future association into land cover, land use, habitat or other classification scheme. These definitions are essential as a means of communicating the signatures in the mind of the Landsat analyst to the other users of the product. They constitute a spectral classification, which is aggregated into land cover and land use classifications.

## 3.2 VICAR Landsat Image Processing

3.2.1 Overview

The processing of a Landsat image with VICAR is generally outlined in Figure 3.2.1. The process is linear except in the "interactive and concurrent" steps of Statistics Evaluation and Spectral Classification. The references to other Figures provide an overview of the detailed process in Figures 3.2.2 to 3.2.7. These figures have a linear progression and each figure subsequent to Figure 4 begins with an output product formed in the preceding figure. The beginning is acquisition of the EDIPS product.*

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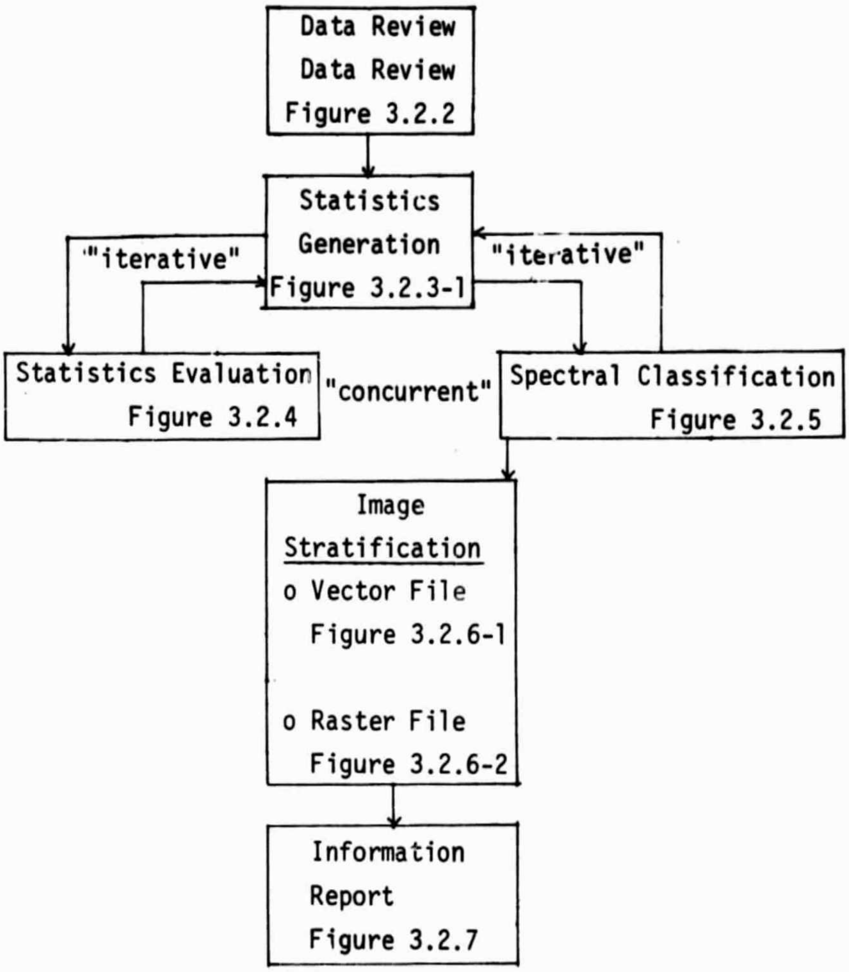
* From the EROS Data Center of the U.S. Geological Survey, Sioux Falls, South Dakota

Figure 3.2.1: VICAR Landsat Image Processing




Data review is essential to provide an understanding of reflectance in the Multi-Spectral Scanner (MSS) data. It is important to find actual points and general geographic location for the spectral responses in the image.

Generation of statistics provides the means and covariance for

spectral signatures. Most of these statistics are needed to make the myriad decisions during computation in spectral classification.

Statistics evaluation is an optional but usual pursuit to improve your first efforts and gain an improved statistics file. The recycling through this step may be concurrent with early classification efforts. Partial image classification is used to test statistics files.

Spectral classification is a product that has a large number of spectral categories applied over the entire image. At this point in the process there is but one land cover definition for a spectral category.

Image stratification consists of a division of the image into separate areas permitting as many land cover definitions for each spectral category as their are strata. Most categories will remain associated with the same land cover class, however. The writing of information reports is the utility of of multi-purpose classification. The association of stratified spectral categories into useful information classifications is now possible. Land cover, land use and wildlife habitat are some examples of information classification.

A more detailed discussion of these steps is necessary to understand which VICAR programs are used. The discussion will not go so far as showing job statements, but will discuss the inputs, outputs and basic logic of the programs used in the process.

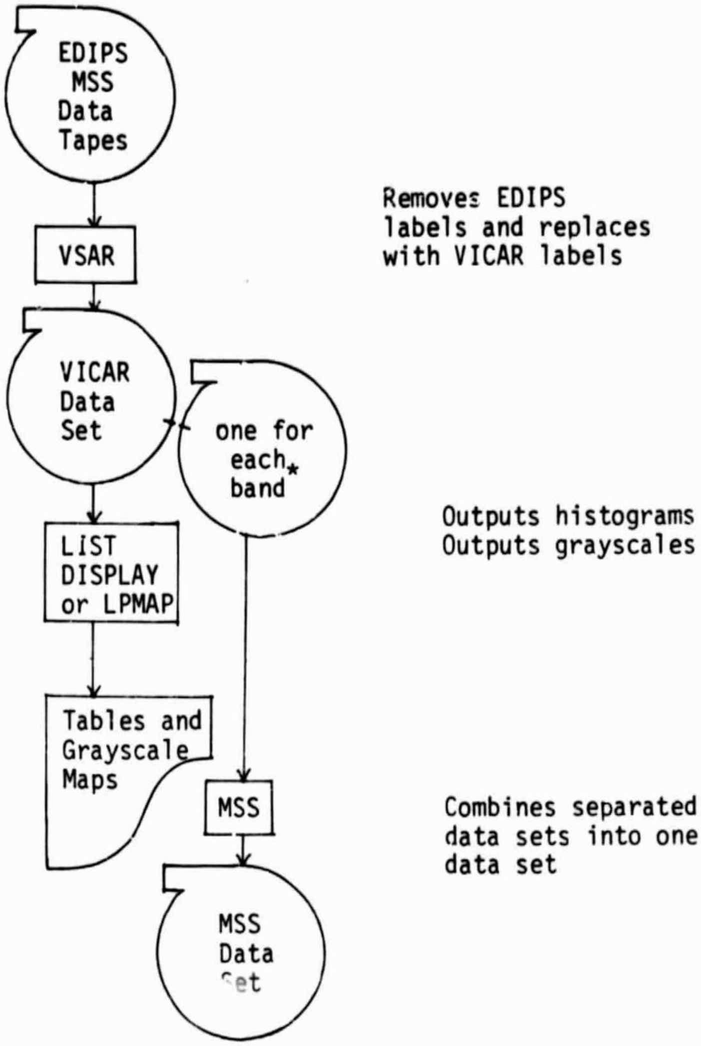
### 3.2.2 Data Review

Spectral and geographic orientation in the Landsat image is the objective. The MSS data tapes are assumed to be EDIPS format precluding a need to VERTSLOG the data. The first program used is VSAR, which removes EDIPS labels and replaces them with VICAR labels, see Figure 3.2.2. The result is a VICAR data set that may be used by any VICAR program which does not begin with "V", since the data set has VICAR labels.

DISPLAY or LPMAP are alternative programs for lineprinter output of grayscale maps. The grayscale maps may be set by selection of DN values from the histograms for each Band. The choice of a DN is usually associated with separation of reflection between two major land cover types, e.g., a DN value of 7 in Band 5 may divide water from conifers. When the grayscale map is inspected by the analyst, it provides locations for later training and land cover types. Also, the grayscale map may provide tiepoints for later registration of the image to a map projection. These results are the geographic orientation desired. (This process is sometimes called density slicing or equidensiometric analysis.)

All of the data review to this point is band by band processing. It is necessary to combine all the bands into one MSS data set before proceeding to statistical routines. MSS is a program that will read the data from separate bands into a band sequential format for more efficient statistical processing of the data.

Figure 3.2.2: Data Review




* Basic Process is for a single Band and must be repeated for as many Bands as are used, 10 maximum.

### 3.2.3 Statistics Generation

Myopic and synoptic vision is a useful analogy to explain the alternatives to statistics generation, see Figure 3.2.3-1. The myopic vision of the analyst pursues the known spectral signatures in the grayscale maps. Training sites are selected with confidence that the pixels represent a known variation of a defined land cover class in a known location. The analyst selects as many training sites as his knowledge permits for a STATS job.

A spectral plot shows the means (centroids) and standard deviations (elipses) in a graph of two bands for each spectral category. The "form" is the expected pattern of distribution derived by review of histograms for each band. The "gaps" are possible omissions in the training that need to be considered for additional training. With a statistics file is considered complete, FASTCLAS can be run to produce a classified map. If doubt exists as to the completeness of the file after more than one spectral plot review, a part of the scene can be classified to see any unclassified area by geograhhic location.

It is usual procedure to do statistics evaluation to assure completeness and separability of the spectral categories before running FASTCLAS. Statistics evaluation will be discussed after the synoptic approach.

A synoptic approach begins with the premise that the data has statistically separable clusters of spectral data. Cluster analysis

is an unsupervised routine that produces spectral categories for a statistics file. The difference from the myopic approach is that the geographic location and land cover representation of a spectral category are unknown at this point.

FASTCLAS with cluster statistics for an area with most land cover classes represented allows a geographic review for the purpose of associating spectral categories with land cover classes. It is expected that several categories will associate with a single land cover class.

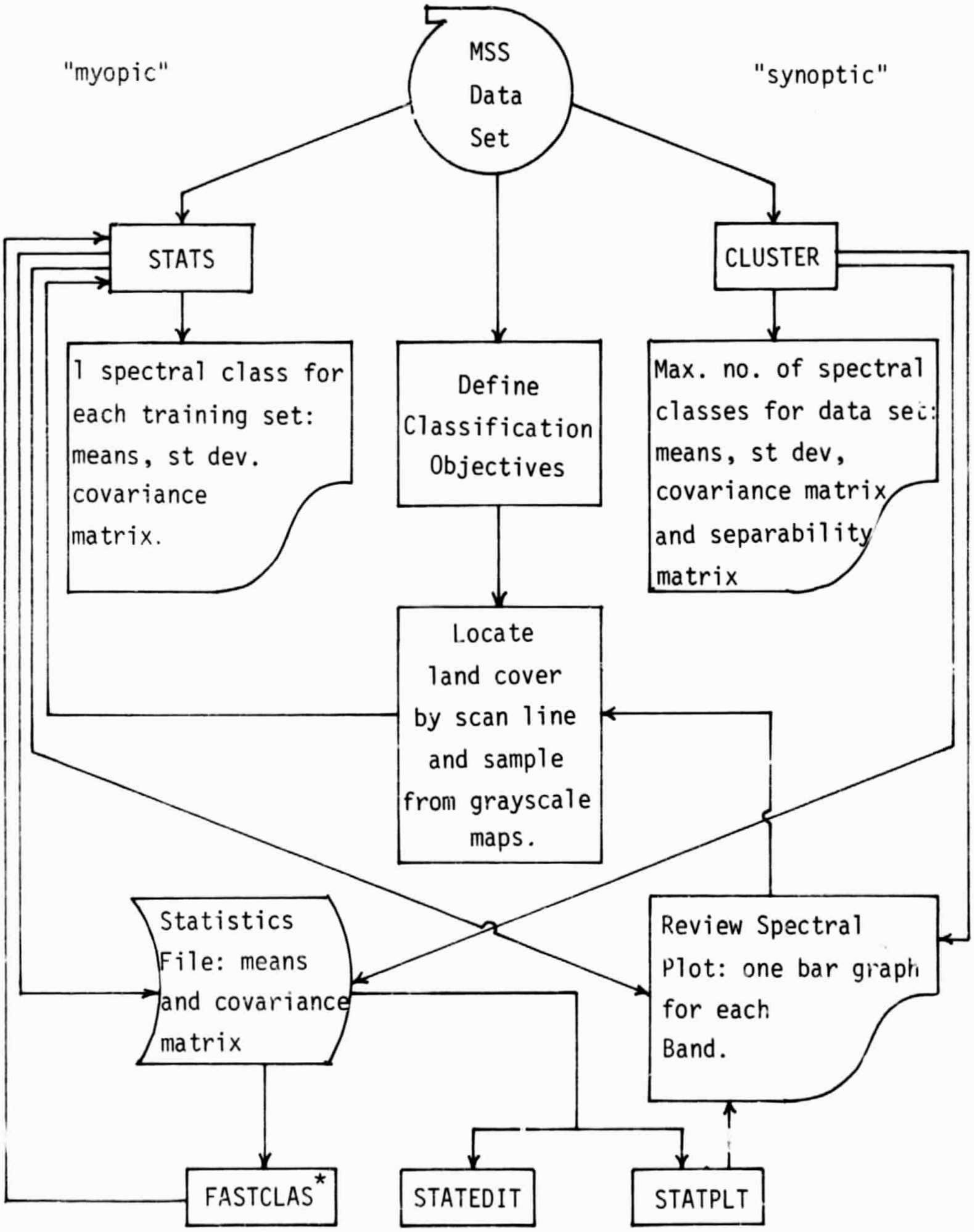
Another review is the spectral plot of CLUSTER statistics. The plot helps the analyst to associate spectral categories with land cover classes. Data review will produce expectations about DN values for each land cover class; and experience with previous spectral plots is the best teacher.

The utility of this multipurpose classification is in being able to reassociate the spectral categories into the information classification desired. Thus, the task of determining what the cluster analysis represents is demanding.

### 3.2.4 Statistics Evaluation

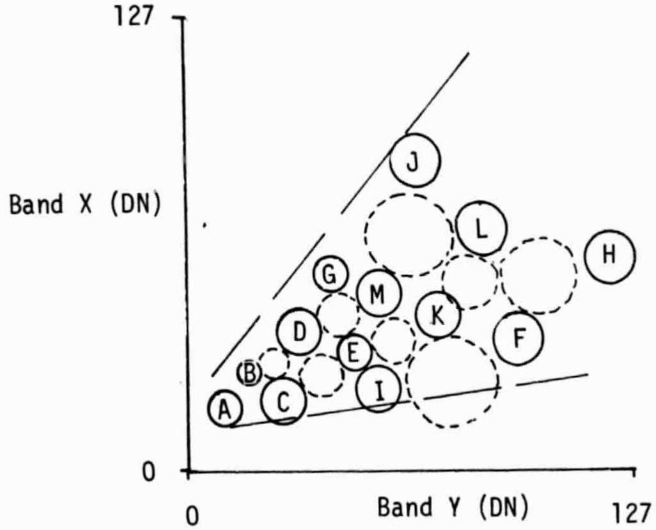
The two routines for statistics evaluation are STATEDIT and STATPLT. STATPLT is used to get the spectral plots that have been discussed in the preceding discussion on the myopic and synoptic approaches.

Figure 3.2.3-1: Statistics Generation




* Classification can be used to evaluate statistics or without statistics evaluation.

Figure 3.2.3-2: Simplified Spectral Plot



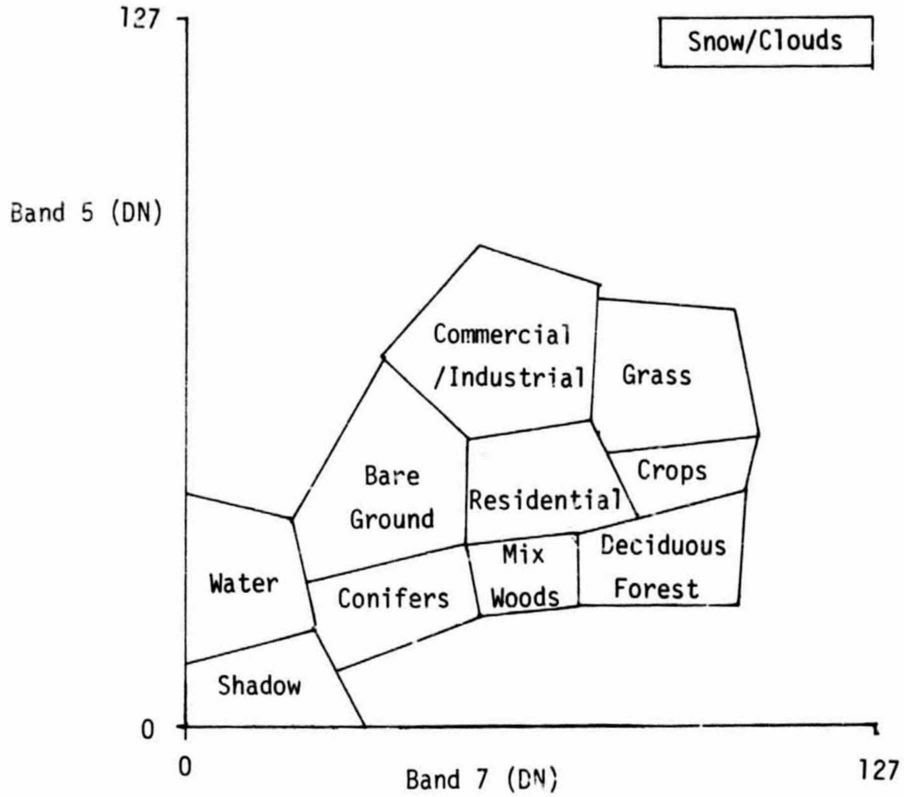

A, B, C = means for each spectral class

= standard elipse

= the "fan" is hypothesis of distribution derived from histograms for each band.

= The "gaps" are possible omission in training

Figure 3.2.3-3: Simplified Land Cover Zones for a Band 5 & 7 Spectral Plot




Zones are hypothetical locations for land cover spectral classes that is derived from data review but mostly by experience.

STATEDIT is capable of copying, combining, deleting or adding multiple files (10 maximum) as subroutines. The output is a separability matrix that can show all the category to category comparison with an index value. A value of 1.0 shows the two categories are separated. Analyst may chose to use values as low as 0.5, which is indicative of overlapping clusters. When low values are used the analyst relies upon the parallelpiped and Bayesian checks in FASTCLAS to make the decision for assigning a pixel to a category (see Spectral Classification).

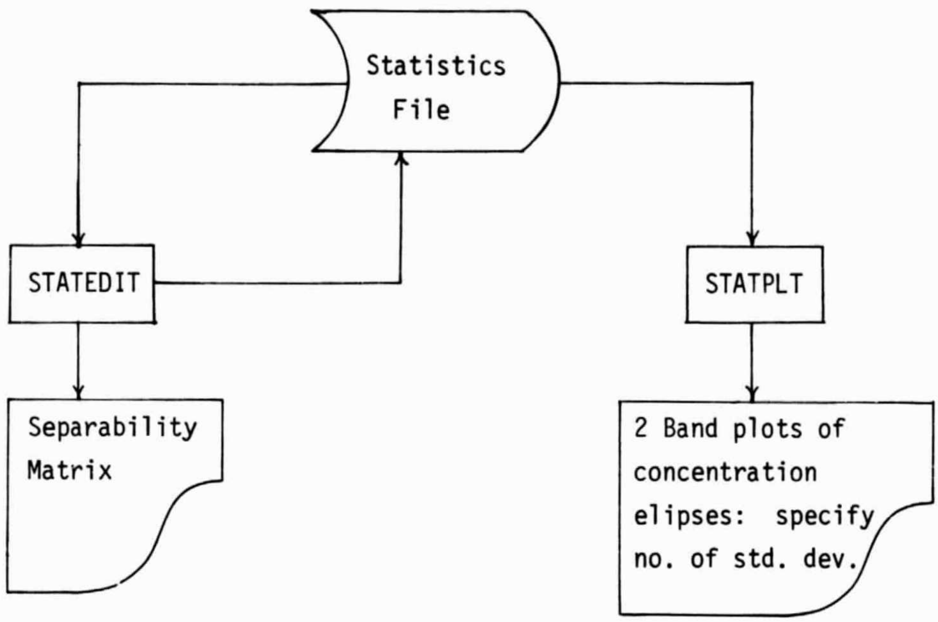
The separability matrix helps the analyst reduce the number of spectral categories. Two variations in a land cover class from the myopic approach may not be valid with this inspection. If so, the two categories can be combined or one deleted. In the synoptic approach, combining categories can be helpful to reduce the length of the statistics file. It is necessary to caution analysts not to do so much combining and deleting that the multipurpose utility is lost.

### 3.2.5 Spectral Classification

Classifying the MSS data set with a statistics file is the major computational step and the most costly. (FASTCLAS in VICAR on the WSUCSC Amdahl tooks 23 minutes for the Puget Sound scene run on a delay priority in two jobs with a cost of less than $900 in 1981, using 71 spectral categories.)

This step is where the computing power of a large mainframe with

Figure 3.2.4: Statistics Evaluation*




* Interactive process resulting in amended statistics files.

VICAR saves money for the agency. But the analyst should be ready the first time (confident the statistics file is ready), because this step is expensive to repeat. Results should be obvious in a color display or similar pictorial review of the classification, and this may dictate revision of statistics and reclassification.

The FASTCLAS routine will begin by computing parallelpipeds from the means and covariances. The parallelpipdes are in a four-dimensional space defined by the minimum maximum reflectance values for each band for each spectral category. If a pixel does not fall into

these limits it is not classified. These limits for different spectral categories may overlap as was suggested in the discussion of using a separability matrix value of less than 1.0. (See Figure 3.2.5.)

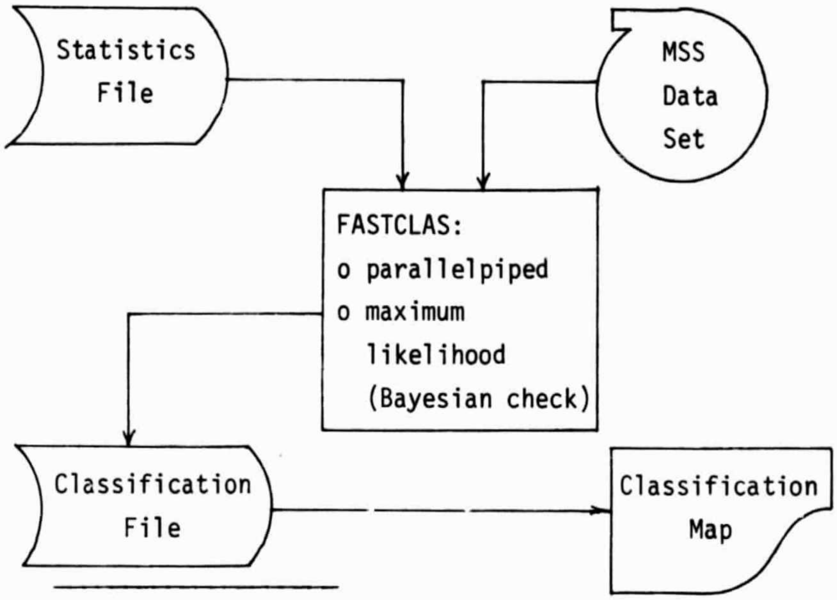
After the parallelpipeds are used to assign pixels to spectral categories, the maximum likelihood or probability approach is used. The overlapping aprallel pipeds leave ambigious pixels that can be assigned after a Baysian check to find the highest probability for its spectral category.

The products of FASTCLAS are a classification file followed by a classification map. The file can be used many times to produce maps that assign colors, characters or grayscale values to individual classes or sets of classes, or both.

### 3.2.6 Image Stratification

The strategies for stratification differ with the analyst's objectives. Basically, the objective is to improve the color information display or the lineprinter map. The elimination of errors of commission is a common objective. For example, the spectral signature for a business district may be very similar to the bare geology between a timberline and a glacier. The displacement of the two in both horizontal and vertical distance allows a strata line to be drawn between the two. It is also critical that business districts are not proximate to timberline and glaciers (usually they are not). Another example may relate

Figure 3.2.5: Spectral Classification*



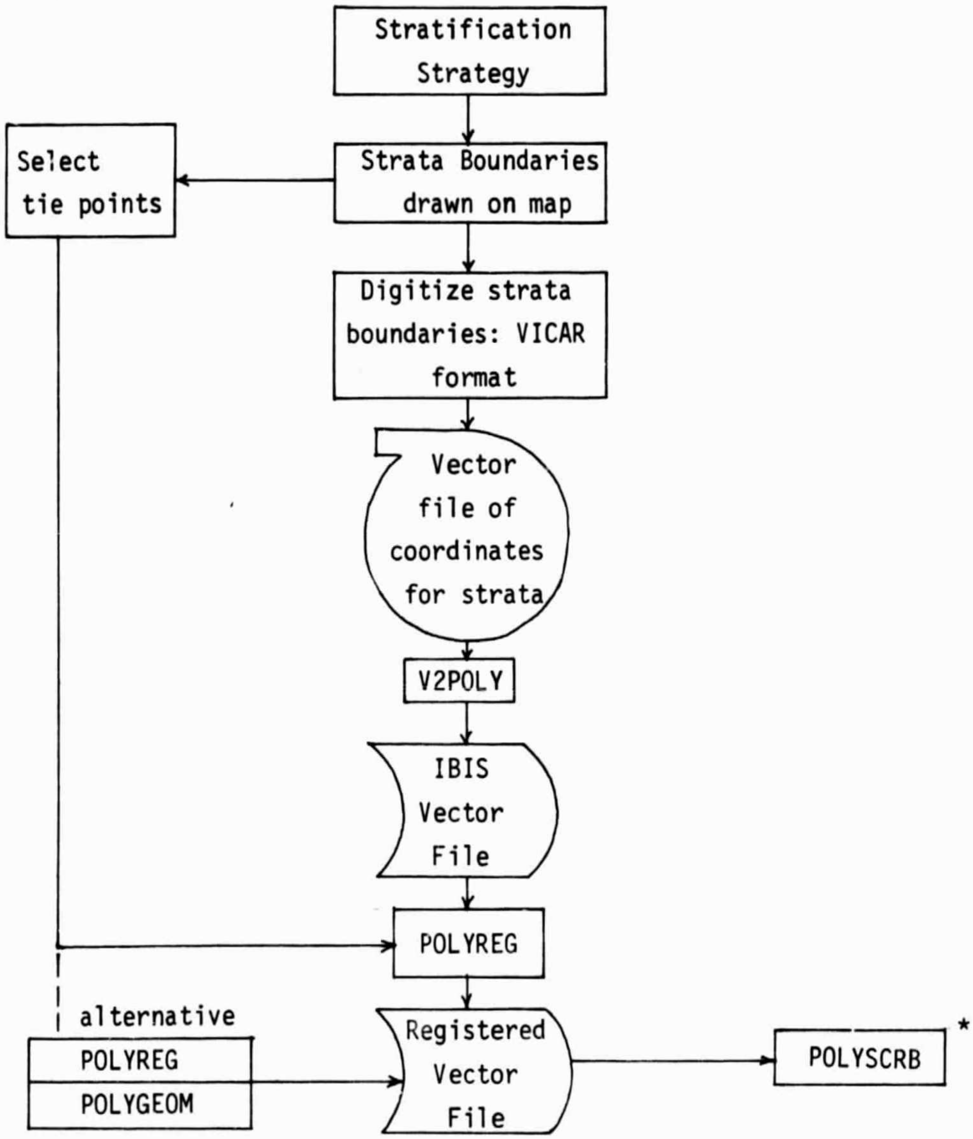

* Iterative process resulting in amended classification file and map.

to elevation of a land unit. For example, the habitat for a species of wildlife map be known to be below 2500' elevation. The 2500' contour can be used to stratify potential habitat and non-habitat. Rural-urban, mountain-prairie and other separations may be objectives for stratification. Regardless of the strategy, lines have to be drawn on a base map.

3.2.6.1 Vector File for Stratification

It is necessary to digitize the strata boundaries as a set of polygons. The vertices of the line ends are stored in a vector file in the digitizing process as sets of coordinates. V2POLY is the program used to create an IBIS vector file.

Figure 3.2.6-1: Image Stratification: Vector File




* A continuous process.

The registration of the boundaries represented in the IBIS vector file is done by a set of tiepoints; as few as three points can be used in POLYREG. Alternatively, a combination of POLYREG and POLYGEOM may be used. The result is a registered vector file.

3.2.6.2 Raster File for Stratification

The conversion of the vector file to a raster image file is done with POLYSCRB. The boundary lines are now associated with pixels, but no data is subtracted. A line is assigned to a row of pixels by randomly including or excluding each pixel.

The raster image file can be displayed with PAINT. A separate density number is assigned to each polygon in the paint file. COLOR can be used to paint the polygons with high contrast between adjacent polygons.

The overlay of the paint file on the classification file is done with F2. The product of the overlay is a stratified classification file.

3.2.7 Information Report

The stratified area is represented by a paint file and the spectral classes are in a classification file. (see Figure 3.2.7.) POLYOVLY is used to prepare an interface file from the two files. The manipulation of the interface file can be done with several programs to reorganize a file, perform mathematical operations or do data addition, concatenation and deletion.

Figure 3.2.6-2: Image Stratification: Raster File

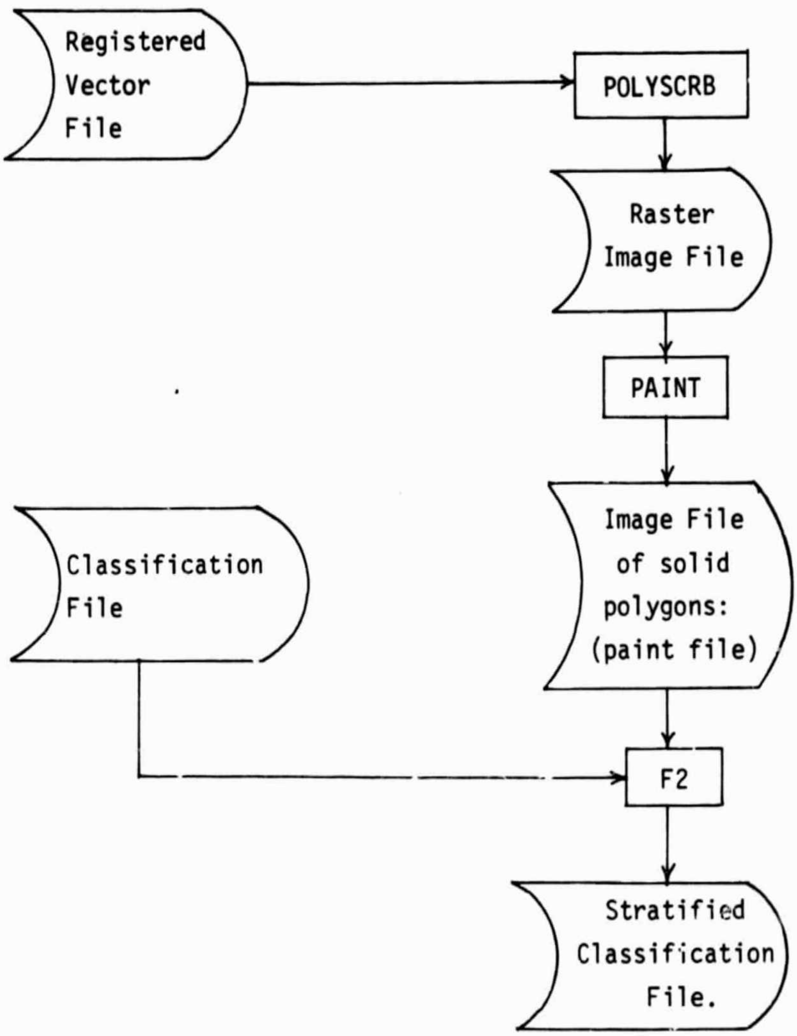
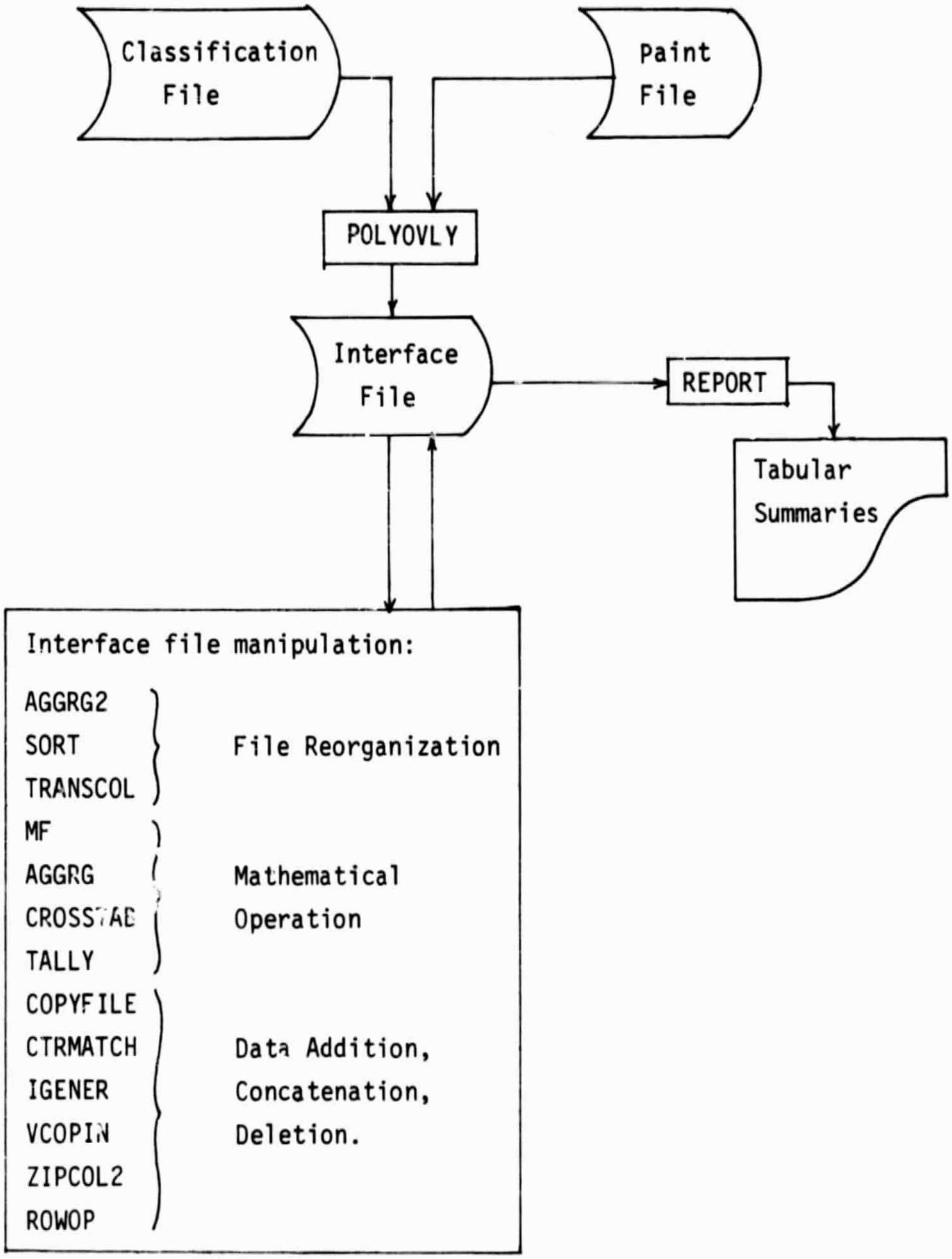


Figure 3.2.7: Information Report



Once the spectral classes have been associated for each of the land cover classes with different associations possible in each strata, REPORT can be used to prepare tabular summaries of the full scene or by strata.

The objective of the classification is to report information such as the percentage distribution of land cover in subareas. The subareas can be prepared in the paint file by the same process used for stratification. Census tracts, traffic zones, drainage basins, political boundaries, game management districts and many other boundary sets can be digitized into a vector file. Following transformation to a vector image file, then a paint file and finally an interface file, information can be obtained in tabular summary as desired.

# 4.0 MULTISPECTRAL CLASSIFICATION

## 4.1 Data Acquisition

Data searches began in December, 1979 and continued through May, 1980. Searches were conducted through the EROS Data Center and the Integrated Satellite Information Services (ISIS) of Canada. The lengthy time period for the search was a result of a backlog of data being transmitted to the EROS Data Center, and the lack of an outstanding, cloud-free scene. Landsat scenes considered for analysis were July 20, August 25, September 12, September 30, October 9, and November 11, all in 1979. Although clouds obscured portions of the southwest quadrant, the July 20 scene (ID-2164018140) was selected because the major areas of interest were cloud free and the sun elevation was high. Also, data for the preceding and following scenes on the same day was available, allowing possible extensions of classification into those areas.

## 4.2 Methodology

### 4.2.1 Classification

A multipurpose land cover classification which would be at least generally comparable with previous classification efforts from 1974 and 1975 was the desired product. The guided clustering approach to classification was selected. In this approach, data from similar preselected training sites is aggregated and subjected to cluster analysis. This is the method which was used in previous

classification work, and the USGS quad maps showing the training sites for the 1974 and 1975 projects were obtained from Mr. Len Gaydos, USGS Geography Program, Ames Research Center, Moffett Field, California. At a meeting in July 1980, representatives of state and local agencies were introduced to the project. They contributed ideas on classification products and structure and were asked to aid in the effort to field check the training sites for changes, which may have occurred since 197— Agency personnel took maps to their office locations, carried out the field checks, and reported the results. Approximately 40 maps with several hundred training sites were processed in this manner.

Training sites were listed by cover type and location in pixel line and sample numbers. This was done with the aid of aerial photos and grayscale maps of the raw Landsat data. All training sites for one land cover type were grouped and used as input data to VICAR program CLUSTER, which develops classification statistics through cluster analysis of input data. The analyst guides the process by selecting the training sites to be clustered, specifying the number of clusters and number of iterations of clustering, and evaluating the output clusters. Since each clustering run included training sites from only one local land cover type, the resulting clusters represented spectral variations of that cover type (spectral clusters). The means, variances and separability values were used in preliminary evaluation of spectral clusters. Clusters with large variances, few samples, or unexpected means

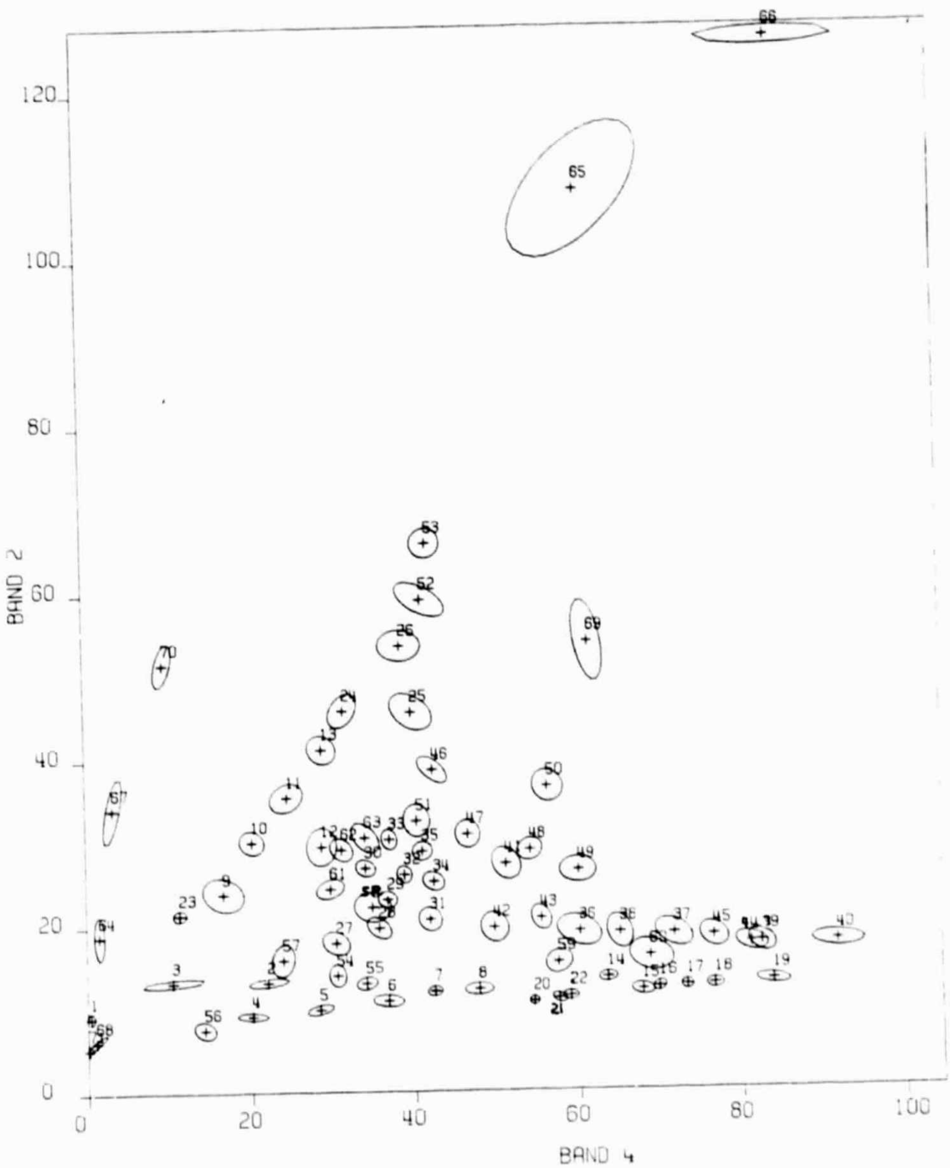
C-2

could be deleted, and low separabilities between clusters indicated the possible need for combining those clusters. Using program STATEDIT, classification statistics from succeeding clustering runs were aggregated. The resulting statistics files were evaluated with separability tables and two-band spectral plots of the spectral clusters. Possible conflicts between clusters of different cover types were addressed.

A number of small subsets of the Landsat scene, usually 30,000 to 60,000 pixels in size, were used to test the classification statistics as they were developed through clustering. These test areas represented a wide variety of land cover conditions and geographical locations, and included sites in Everett, Port Townsend, Seattle, Tacoma, Nisqually/Fort Lewis, Olympia, Skykomish, Lake Tapps, Renton, Mount Rainier, and Wier Prairie. Many classifications runs on test areas were used as the statistics file was expanded. Evaluation of the results was used to add, delete or combine spectral clusters. An iterative process of clustering, evaluating statistics, test classifying, and statistics editing was used to build a master classification statistics file. After major steps at 44, 50, and 64 spectral clusters in the statistics file, a final set of 71 clusters was selected for classification of the entire Landsat scene (See Figure 4.2.1).

The final classification run and all test classifications were done using program FASTCLAS. This program processes the data through a 4-dimensional parallelpiped decision-array corresponding

Figure 4.2.1: Clusters Plotted by Means and Standard Deviation for Red Color (Band 2) and Color Infrared (Band 4).



to the means from the classification statistics file and analyst specified decision boundaries (standard deviation values). If a pixel falls outside the decision boundaries for all classes, it is assigned to the unknown class. A pixel that falls within the decision space for more than one class is resolved by a Bayesian maximum likelihood algorithm. Because of record length restrictions in temporary storage, it was necessary to split the scene into two parts and mosaic them together after each was classified. The classification of all the data (8,949,000 pixels) was done on the Amdahl 470-V8 at WSUCSC in 22 minutes and 50 seconds of CPU time at a cost of $866.

### 4.2.2 Stratification

A tape of the classified image (71 spectral classes) was taken to the Interactive Image Processing Lab, then located in Olympia, for viewing on the color display system. Some problems were noted during the development of the classification statistics, and it was anticipated that stratification of the classified image would be necessary. The major problem was one of confusion between some bare ground and rock classes and certain commercial or residential classes. Viewing on the color display was used to analyze the extent and location of problem areas, and to facilitate the placement of the stratification boundaries. Five geographic strata — urban, rural, agricultural, dry prairie, and mountain — were mapped at a scale of 1:250,000. The strata boundaries were digitized on the Altec digitizer at the University of Washington Academic Computer Center and transferred on tape

to WSUCSC. The strata boundaries were then registered to the classified image and scribed onto a matching blank image. All pixels in the polygon representing a particular strata were coded so that a unique value represented each of the five strata. By overlaying the classified image and the strata polygon image, each of the 71 spectral classes could be assigned to the proper land cover class for each strata. In the stratified output image, pixels were assigned to one of 34 land cover classes (see Figure 4.2.2).

### 4.2.3 Registration

The final task was registering the stratified classification to a UTM grid. Tiepoints were selected by inspecting lineprinter output, aerial photos, maps; and their image line and sample and corresponding UTM coordinates were recorded. A total of 23 points, distributed over the image, were selected. TIECONM, a VICAR tiepoint formatting program, was used to convert the selected tiepoints to a regular grid of points to be used for registration. Program MGEOM was employed to resample the classified image to the new projection. UTM registered images were produced in two forms. The first was an image with 57 meter square pixels to be used on color display systems and for photo products. The second was an image with a pixel size of 76.2 X 60.96 meters calculated so that a lineprinter output of 10 characters per inch and 8 lines per inch would have a scale of 1:24,000.

Figure 4.2.2: Stratified Land Cover Classes

| Dn | Class | Dn | Class |
|---|---|---|---|
| 0 | unclassified | 18 | commercial/industrial |
| 1 | water | 19 | commercial/industrial |
| 2 | sedimented water | 20 | rock with scattered trees |
| 3 | old conifer | 21 | bare rock |
| 4 | conifer | 22 | bare - vacant city |
| 5 | conifer | 23 | bare ground |
| 6 | conifer | 24 | bare - tidelands |
| 7 | deciduous | 25 | snow |
| 8 | deciduous | 26 | clouds |
| 9 | decidous | 27 | shadow |
| 10 | deciduous | 28 | dry grass and brush - prairie |
| 11 | mixed forest | 29 | wetland |
| 12 | mixed forest | 30 | bare with some brush - clearcut |
| 13 | grassland | 31 | brush with some bare ground - clearcut |
| 14 | cropland | 32 | regrowth - older stage |
| 15 | brush and open woodland | 33 | regrowth - younger stage, tall brush |
| 16 | residential - dense | 34 | mountain meadow and shrub |
| 17 | residential - light | | |

# 5.0 VERIFICATION OF LANDSAT CLASSIFICATION

## 5.1 Types of Tests

To err is human.... The possibilities for human error are always present, regardless of how sophisticated a system becomes, In fact, it is possible to postulate that a "point of diminishing returns" may be reached in the pursuit of more sophistication, i.e, the more sophisticated method may be poor understood and applied wrongly. We have set up to tests. One is accuracy and the other is validity.

### 5.1.1 Accuracy and Types of Errors

We want to verify the accuracy of a land cover classification. What kinds of errors could we make?

1. Is the assigned class the right one? If we have assigned the wrong class, we have committed an error. This error is an error of commission. Coversely, we should have given the area a class assignment which we have omitted. We have an error of omission, too. Since we do not want to double count our errors, it is necessary to decide whether we will count errors of commission or omission.

2. Is the location of the class right? In this case we have placed the information on the map in the wrong location; this is an error of placement. Errors of placement are human errors that occur randomly.

A more general view of the same type of error may be the lack of alignment of two different map projections. The latter gives us an

error of registration, which may apply to many points in the map and be explainable or even correctable with an algorithm.

3. Is the control right? Is the "ground truth" true? These two questions are the same. If a person is sent to the field to look at a pixel, how confident can we be that the right pixel was found? How confident can we be that the right interpretation of the land cover was made? How confident can we be that the interpretation was recorded accurately? If we used photointerpretation as a control, do we have all the possibilities of errors of commission and of omission as in the digital classification, which we have set out to test? Would it be likely that errors of placement and errors of registration were also present? The answer to all of these questions is "yes."

At best all we can say of our comparison of a digital land cover classification and a photointerpreted control is that a high level of correlation exists between the two. It is not possible to say that one is right and the other is wrong.

### 5.1.2 Validity and Logic

Another problem is the one of validity. The logic of the process is at stake in this inquiry. We want to defend the product as valid.

1. Is the classification approprite to the task assigned? In this situation, we want to know whether the particular classes have meaning as an informational product in a decision-making setting. In designing the classification, we have identified certain features

of the surface for which we would like to have areal measurements. Thus, we are pertinent.

Because an area of the surface is involved, we must generalize several objects into a land cover class. Photointerpreting certain objects and their associations leads us to conclude that the class assigned is the right one and no other. We have generalized while satisfying the test of mutual exclusiveness between classes.

2. Does the classification represent reality? Yes, if the final classification represents the continuous surface of data that is observable. If the classes are so general that vital information has been deleted, this error of omission produces arbitrary results. If the mapping unit is so large that assigning one class or another could be decided by the flip of a coin, or the statistical sets are so overlapping that probability is used frequently to decide which class is assigned, ambivalence between classes may be present.

### 5.1.3 Why We Verify

It is vital that the Landsat products be verified. Verification is a responsibility that a new technology bears, regardless of the lack of it in traditional information sources. The task is not easy in the face of several methods with no consensus of which way is right. Further, the statistical demands of confidence levels and sampling are not easily satisfied for most user agencies. In the case of a demonstration like the 1980 Land Cover for the Puget Sound Region,

it is necessary that the task be undertaken.

## 5.2 Verification Method

### 5.2.1 Pixel Group Samples

Sampling of pixels groups is the selected method for our verification of the full classified scene. We sought 200 samples in the classified area, and each sample contained 12 pixels. Every effort was made to find a specific point on the ground which represented the upper left hand corner of the cluster on the USGS 1:100,000 maps. The same point in the U-2 photography and in the lineprinter output at 1:24,000 was sought.

The sample is small in that the final number of samples is only 203. The area represented by the samples is 7 acres. The area classified contained approximately 7.2 X $10^6$ acres. Therefore this is only a .02% sample.

### 5.2.2 Photointerpretation of the Control

The photointerpretation of the samples was an involved task conducted by Ms. Malgorzata Mycke-Dominko of the Polish Remote Sensing Center in Warsaw. As a part of her experience on an exchange between the University of Warsaw and the University of Washington she completed the photointerpretation of the samples. Her salary was outside of the NASA Agreement and her assistance was most appreciated.

5.2.2.1 Alignment of Maps and Photos

The points in the sample were located for 375 random kilometer intersections on the 1:100,000 maps. A transparent overlay with 10-kilometer UTM grid intersections was positioned using the 10-km ticks on the maps. A sliding one-kilometer grid was used to identify and pin prick the point. The larger number of samples than those sought was a function of the declination of the Landsat image to north creating a background area. A Minitab random integer sampling routine was used to sample all possible one-kilometer grid intersections.

The U-2 photography and the maps were aligned using an optical transfer scope. The area in the cluster approximates 7 acres. The land cover was recorded in a Level I classification by drawing choropleths on an enlarged square representing the cluster.

5.2.3 Location of the Samples in Lineprinter Maps

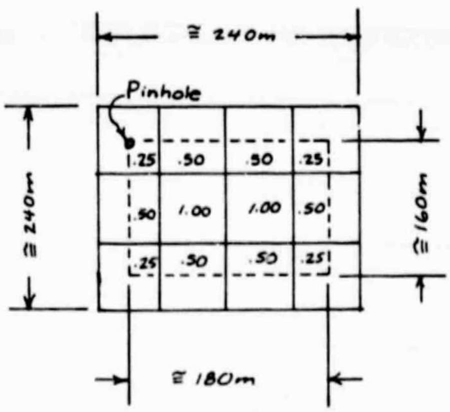
5.2.3.1 Translation of UTM Coordinates to Line and Column Coordinates

The pixel in the upper left hand corner of the resampled classification was found using a routine that translates Universal Transverse Mercator map coordinates into the pixel scan line and sample coordinates. The residuals in the translation were small enough to expect that the scan line and samples were in error by less than one pixel.

5.2.3.2 Pixel and Cluster Alignment

The center of the pixel was judged to be the same location as the pin hole in the map. The photointerpreted cell is shown in Figure 5.2.3.2. Also shown in the drawing of the cell is the grid representing all the pixels and their individual vote shares. The vote share was used to decide the class of the photointerpreted cell as represented in the Landsat classification.

Figure 5.2.3.2: Cluster of Pixels in a Sample




5.2.4 Objective Rules for Comparison

5.2.4.1 Assumptions

Rules were written to objectify the comparison of the photointerpretation and the Landsat classification based on the following assumptions:

1. The photointerpreter used the same ten classes that were used in the digital classification. The eleventh class in the Landsat classification was "unclassified."
2. The photointerpreter and the Landsat classifier agreed on

the particulars of the land cover signatures.

3. The center of the pixel in line and sample coordinates is the upper left hand corner of the photointerpretation cell.
4. The sample is a three by four matrix of pixels as shown in Figure 5.2.3.2.
5. Pixel location is within one pixel in line and sample.

5.2.4.2 Four Rules

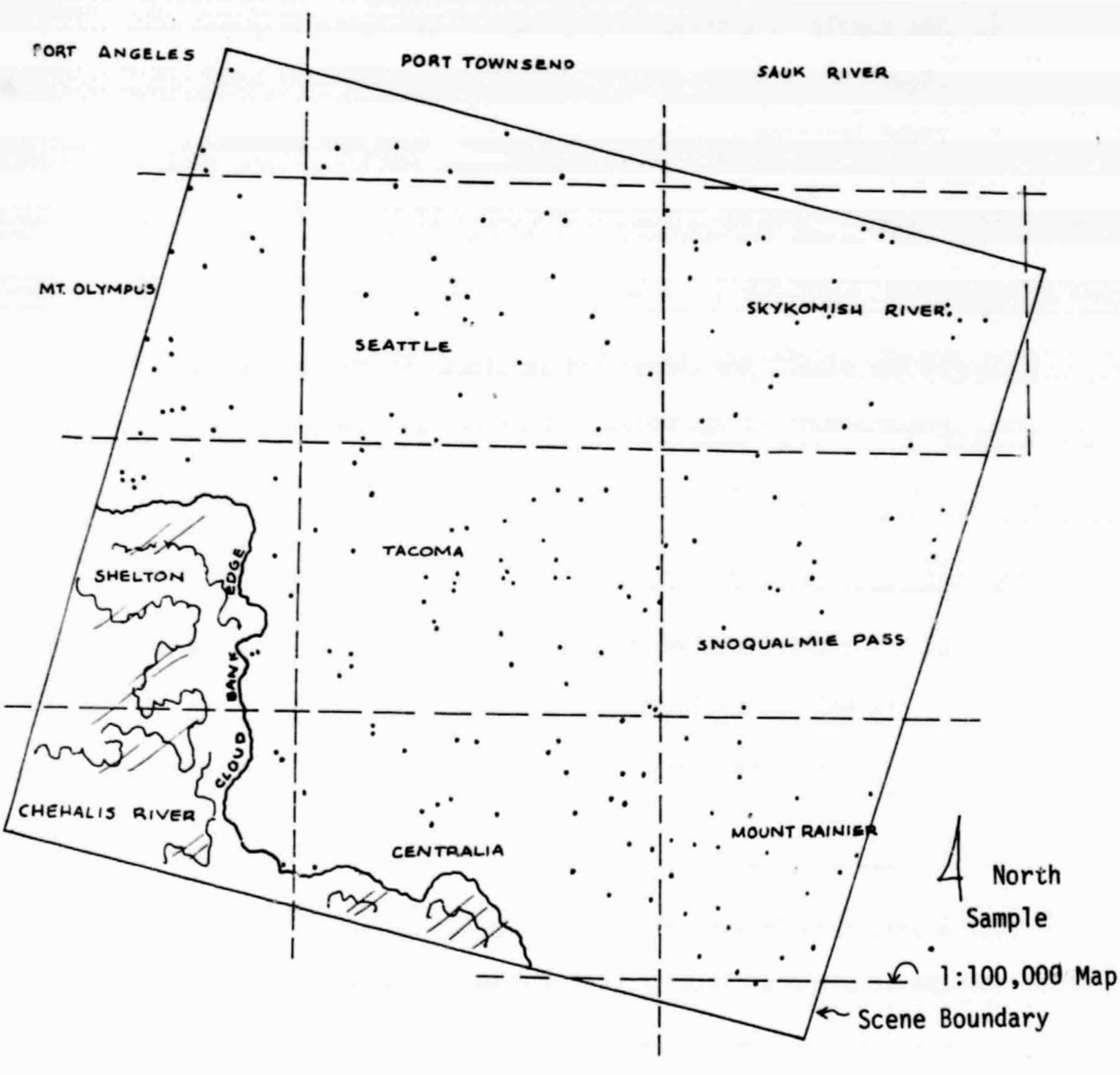
The rules are:

1. If any pixels are classified as clouds in the sample the whole sample is discarded. An exception is allowed in the Mt. Rainier area where snow was expected to occur and no clouds were expected.
2. Dominant class is determined by a pluralistic decision.
   a. In the photointerpretation the dominant class is the largest class in the cell.
   b. In the lineprinter sample the most votes is the dominant class. The vote shares are shown in Figure 5.2.3.2 and the total count is 6.
3. A sample is "mixed" if no decision can be made. Less than 33% in any one class is a case with less than 2 votes for a class and the result being a "mixed sample.
4. Shadow associated with conifer is also conifer.

5.2.5 Sample Size

5.2.5.1 Random Sample

Figure 5.2.5.2. Map of the Cluster Samples



The overall verification of the Landsat classification was done with a random sample of 12-pixel clusters. As described earlier, an integer random sampling routine was used to select the sample locations from among all possible one-kilometer grid intersections, See 5.2.2.1. Minitab's routine includes replacement of the number selected in the sample. The number of samples taken was 375 to allow for background area and clouds. It was estimated that the remaining samples in the classified area would be large enough to provide a confidence limit of 95 for the accuracy objective of 85%.

5.2.5.2 Location of the Cluster Samples

The sample is shown in Figure 5.2.5.2 in the grid layout of the 1:100,000 scale map series. Only the samples falling inside of the classified area (203) are shown. The approximate extent of the cloud cover is also shown.

5.2.5.3 Equation for Sample Size

The sample size was checked by using the equations in the Fitzpatrick-Lins paper (USGS Circular 829). The formula is as follows:

$$N = \frac{4pq}{E^2}$$

when:

| | |
|---|---|
| N = number of samples | q = 100-p |
| p = percent of accuracy | E = allowable error |

5.2.5.4 Allowable Error

Allowable error is based on the scale of the maps being used. In this case, we accepted 2.5% error above and below the percent of accuracy in the sample:

$$E = 2 \times 2.5 = 5$$

Had an allowable error of 2% been used as found in the Fitzpatrick-Lins report, three hundred fifteen (315) samples would be required.

5.2.6 Confidence Limit

A 95 percent one-tailed lower confidence limit for a binomial distribution was found by using the Fitzpatrick-Lins formula as follows:

$$p = \hat{p} - \left\{ 1,645 \sqrt{pq/n + 50/n} \right\}$$

where:

$p$ = accuracy of the classification - percent.

$\hat{p}$ = accuracy of the sample - percent.

$\hat{q}$ = 100-p

$n$ = sample size

The number of correct samples was one hundred ninety (190) of two hundred three (203) or:

$\hat{p}$ = 93.596

$\hat{q}$ = 6.404

$p$ = $\underline{\underline{90.523}}$

### 5.2.7 Level I Classification for Overall Verification

The number of samples that are correct is only the start of describing the results. In Table 5.2.8, the photointerpretation is compared to the Landsat classification in a contingency table or a "truth" table. The ten classes of the photointerpretation are not strictly a Level I classification as defined by Anderson. It would require a stratified sample to verify the smaller classes. If all the urban and built-up classes were grouped and all the forests were grouped it would not eliminate the need for a stratified sample. The overall percentage correct would be higher if a strict Level I classification were used. But the objective of the project was to replicate the 1975 work and set up the prospect for change detection. Thus, the classification developed by the agencies was used.

### 5.2.8 Contingency Table

A contingency table was set up to compare the photointerpretation to the Landsat classification on a class by class basis. The overall accuracy holds up with 90.5% accuracy. Small classes like commercial/industrial were too small to judge. The misclassification of commercial/industrial as residential was acceptable since both are urban/built-up cover in Level I. Similarly, the misclassification of deciduous as brush was acceptable in Level I.

### 5.2.9 Parameters for the Landsat Scene

The following parameters are used in the Landsat scene for the

Table 5.2.8: Contingency Table, 1979 Land Cover Classification

| PHOTOINTERPRETATION CLASS | LANDSAT 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| 1. WATER | 28 | | | | | | | | |
| 2. CONIFER | | 82 | | | | | | | |
| 3. DECIDUOUS | 1 | 1 | 24 | 1 | 4 | | | | |
| 4. GRASS/CROP/PRAIRE | | | | 16 | 1 | | | | |
| 5. BRUSH | | | | 1 | 15 | | | 1 | |
| 6. RESIDENTIAL | | | | | | 6 | | | |
| 7. COMMERCIAL/INDUSTRIAL | | | | | | 2 | 1 | | |
| 8. BARE | | | | 1 | | | | 16 | |
| 9. SNOW | | | | | | | | | 2 |

* MAP ACCURACY AT LOWER 95% CONFIDENCE LIMITS IS 90.5% = p.

Puget Sound Region.

Raw Data

Pixel size: 57 by 57 meters

Pixel count: $10 \times 10^6$

Classified Land Cover

Pixel size: 61 by 76 meters = 0.802 acres

Pixel count: 6,259,482

Cloud cover: 690,285

Cloud cover: 12,39%

Pixel count less cloud count: 5,569,197

Number of samples: 203

Acres per sample: 7

Acres of scene (cloud free): 4,469,109

Area of all samples: 975 acres

Size of sample: 0.02%

Lineprinter scale (10 cpi X 8 lpi) = 1:24,000

## 5.3 Mountain Conifer Field Survey

### 5.3.1 Summary

This task was carried out cooperatively with the Washington State Game Department. The land cover classification contained six spectral classes (out of 71 total) which represented conifer forest. The six classes were distributed over a rough continuum of old to young conifer forest. The objectives were to test the accuracy of the conifer class in general, and to collect detailed

field data to correlate specific conifer community types with each spectral class.

5.3.2 Methodology

Large blocks of the land cover classification were output on a linepriner at a scale of 1:24,000. Areas for printing were selected by inspecting conifer forest on aerial photos. Areas selected were Mt. Rainier, Deception Pass and Surprise Creek (Alpine Lakes Wilderness), Skykomish (Beckler River), Carbonado, Hood Canal (Mt. Walker), and Sumner. Sites for field visits were identified by picking large blocks of pixels (50 or more of the desired class) in areas of reasonable access. The initial goal was to visit at least 5 sites of each of the 6 spectral classes. More sites were selected later to collect additional data for some classes. At the conclusion of the field effort, 56 sites had been visited distributed among the spectral classes as follows: Class #56 — 5 sites; Class # 4 — 7 sites; Class # 5 — 16 sites; Class # 6 — 11 sites; Class # 7 — 8 sites; Class # 8 — 9 sites.

The locations of the sites were transferred to 1:24,000 topographic maps. An observer visited each site in the field using the line-printer map and the topographic map for navigation. Typical data for each site collected in the field is shown on the sample data sheet, Figure 5.3.1.

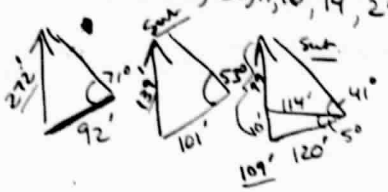
5.3.3 Results

All sites were successfully located in the field and were reverified

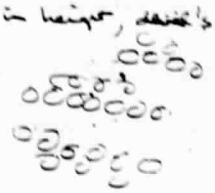
Figure 5.3.1: Sample Field Data Sheet

Site #16 – Skykomish Area X 19 Aug 1981
Spec. Cluster 56 –
DBH – 35.9, 26.7, 39.5, 31.0, 33.8, 43.2, 42.2, 43.5, 45.7, 47.2
34.5, 53.0, 36.7, 40.0, 33.2 Ave. – 39.1
Dist. between trees – 15, 25, 17, 16, 14, 24, 12, 30, 15, 5, 29, 30, 17, 39, 3[illegible]
. Ave – 21'

height.
multilevel




Understory – many young hemlock trees – (10–15 feet in height, devil's club, Vaccinium, berries, etc.
the trees are arranged around light areas



Core Sample # 16D – DBH – 18.5
Hemlock Age – ≈235

SCENE I.D. CWW COUNTY King

USGS QUAD NAME Scenic, WA

AREA NAME Deception Pass Trail UTM COORDS (X) 638
(Y) 5287

SLOPE 5° W/E Site

ASPECT ______

ELEVATION 1,800'

DOMINANT TREE SPP. Hemlock/Douglas fir AGE 400+ (?) HEIGHT 272' Ave DBH 39.1

SUBDOMINATE TREE SPP. Cedar/Hemlock AGE 235 (DBH – 18.5) HEIGHT 139'

STAND TYPE: CONIFER DECIDUOUS MIXED

% CANOPY CLOSURE 60

CANOPY CHARACTERISTICS A B C D (circle appropriate class )

AVE. DISTANCE BETWEEN DOMINANT TREES 21' (ave. of 16 measurements)

100% as being conifer forest. Results are tabulated in Table 5.3.2. As expected, spectral Classes # 56 and # 4 were old growth stands and included both climax hemlock (Tsuga heterophylla) and old growth Douglas-fir (Pseudotsuga menziesii) forests. There was little difference between Classes # 56 and # 4 except that Class # 56 appears to be found on north facing slopes indicating a more shadowed spectral response. These two classes are also found to a limited extent at 3,500 to 5,000 feet indicating subalpine fir (Abies lasiocarpa)/mountain hemlock (Tsuga mertensiana) stands. A dichotomous breakdown was observed in Classes # 5, # 6, # 7. The difference between managed and natural stands in terms of physical stand parameters as shown in Figure 5.3.2 is striking, but spectrally the two types are very similar. Above 3500 feet, which is above nearly all managed stands, Classes # 5, # 6, # 7 and # 8 represent subalpine forests of mountain hemlock and subalpine fir. Class # 5 (older, larger trees) and Class # 8 (younger, smaller trees) are at the ends of a continuum of subalpine forest conditions. Class # 8 is rare in these high altitude stands. Below 2000 feet, Classes # 5-# 8 nearly always represent second growth, managed stands of Douglas-fir, with a progression to younger stands moving from Class # 5 to Class # 8. Between 2000 feet and 3500 feet, Classes # 5 through # 7 can represent either natural fir/hemlock forests (Abies amabillis/ Tsuga heterophylla) or managed stands of second growth Douglas-fir.

In large areas covered by the Landsat classification, the spectral separation alone will not yield the level of information needed

Table 5.3.2

FIELD SURVEY RESULTS
CONIFER CLASSES

Spectral Class

| STAND PARAMETER | 56 | 4 | 5 natural | 6 natural | 7 natural | 8 natural | 5 managed | 6 managed | 7 managed | 8 managed |
|---|---|---|---|---|---|---|---|---|---|---|
| Height of dominants, ft. | 176 | 167 | 137 | 145 | 100 | 69 | 133 | 126 | 79 | 88 |
| DBH inches | 33.6 | 34.7 | 30.7 | 21.8 | 15.8 | 11.2 | 18.0 | 15.2 | 10.2 | 9.6 |
| Age years | 400+ | 300+ | 275 | 200 | 160 | 75 | 71 | 67 | 34 | 42 |
| Distance between dominants, ft. | 26.6 | 26.4 | 20.6 | 10.6 | 12.0 | 7.4 | 17.0 | 13.5 | 8.8 | 8.6 |
| Canopy closure, % | 56 | 64 | 68 | 82 | 80 | 75 | 78 | 72 | 91 | 94 |
| Stand type | D | D | D | C | C | C | B | B | A | A |
| Majority aspect of field sites | N | S,W | ? | S | S | S | S | N | ? | ? |
| Elevation range of field sites | 1800-4900 | 1200-4900 | 2000-4900 | 2900-4400 | 3100-3700 | 3300-4800 | 1000-3700 | 100-3700 | 100-3400 | 100-3700 |

for applications such as detailed wildlife habitat management. Other layers of information to refine the classification are needed, and it appears that physical data such as slope, aspect and elevation would not be sufficient. Years of harvesting and forest regeneration have disrupted the natural patterns of forest communities over large areas. Along with elevation, an information layer that connects forest management practices to the land is needed. Currently, a mapping of ownerships and/or management agencies is under consideration for use as one layer to refine the classification.

## 5.4 Urban Comparison of 1975 and 1979 Classifications

### 5.4.1 Selection of Window: Renton Area, South King County, Washington.

Because of the analyst's familiarity with area and because the area is known to have undergone change over the four year period, Renton was selected. The final window size is more than large enough to accomodate all of Renton's borders and planning area. Actually, it is large enough to include several lakes so that geographic location can easily be found.

### 5.4.2 Common Classifications of Land Cover for 1975 and 1979

Classification categories were reduced to approximately Level I categories. This reduction was done to enable distinction of change categories. The resulting 8 X 8 classes leave 64 possible change categories. The original 34 X 52 categories would have been untenable. Also Level I is appropriate, considering the resolution of Landsat. The final classes are:

1. Unclassified
2. Barren
3. Water
4. Wetlands
5. Woods-forest
6. Open (agriculture, grass, etc)
7. Residential
8. Commercial (including 1975 pavement class)

### 5.4.3 Registration

Because the 1975 image was registered to USGS quads, we chose to register the 1979 to the 1975 image. At the time the 1979 was unregistered, but it was stratified. The methodology was to select a number of tie points, from both images. Care was taken to insure that the same pixels, representing the same locations, were selected, we used Vicar programs TECONM and MGEOM for this processing. MGEOM is appropriate for this task as it has the option of using only nearest neighbor for assigning pixels to their new positions, which must be done when one is using a classified image.

This process took three iterations to reduce the residuals, to less than 1 pixel.

Also, note that tiepoints were selected from a larger window than the final 164 lines X 220 samples window, to avoid possible problems with distortions around the edges of the window.

### 5.4.4 Image Superimposition

Once the images were registered, a smaller window was cut to encompass the greater Renton area north from Angle Lake, encompassing the southern tip of Mercer Island, east to a point that allowed the intersection with a line drawn north from Lake Youngs, with the southern boundary connecting Angle Lake to Lake Youngs.

Then it was a simple matter to use F2 to add the 1979 to the 1975 and come out with distinct classes of change. For example, class 22 on the image indicates that there was no change—that both classifications show the same class. (WATER-WATER) Class 31 shows a change from class 3 to class 1.

### 5.4.5 Interpretation

Obviously, some changes would seem illogical at the outset, e.g., a barren pixel to forest. In the present aggregated HISTOGRAM from, there is no reference to the geographic location of the individual pixels; conclusions should be preliminary until the process of verification by comparison with ground truth is completed. There are several distinct possibilities:

(1) For those that show no change, both could be wrong.

(2) For those that show change, either or both could be wrong, i.e., a water 1975 may actually be land, and so the land class in 1979 is correct. Also, it may be seen that both were wrong and that it was wetland.

### 5.4.6 Histogram Comparisons

A histogram produced and all changed classes were stretched to class zero (0). Class 0 comprises 41.7% of all the pixels. That is, about 42% of the pixels in this area are shown to have undergone some sort of change. (See Figure 5.4.6.)

There will be some errors of omission or commission in the 58% that are listed as 'no change,' probably a relatively small

percentage. The 42% changed pixels surely can't all be wrong.

The study is not yet verified. The purpose of Mr. Kerry Brooks' in his masters thesis is to separate error from change.

Figure 5.4.6: Histogram Showing the Percentage Comparison of 1975 and 1979 Land Cover Classifications (Level I) in Renton, Washington

FREQUENCY HISTOGRAM - NORMALIZED TO MAXIMUM = 100 (LEVELS WITH ZERO FREQUENCY OMITTED)

| GRAY | FREQ | PERCENT |
|---|---|---|
| 21 | 3 | 0.008 |
| 22 | 17 | 0.047 |
| 23 | 30 | 0.083 |
| 25 | 7 | 0.019 |
| 26 | 5 | 0.014 |
| 27 | 42 | 0.116 |
| 28 | 75 | 0.208 |
| 31 | 25 | 0.069 |
| 32 | 9 | 0.025 |
| 33 | 2003 | 5.552 |
| 35 | 2 | 0.006 |
| 37 | 10 | 0.028 |
| 38 | 32 | 0.089 |
| 41 | 29 | 0.080 |
| 42 | 34 | 0.094 |
| 43 | 121 | 0.335 |
| 44 | 1 | 0.003 |
| 45 | 18 | 0.050 |
| 46 | 10 | 0.028 |
| 47 | 69 | 0.191 |
| 48 | 60 | 0.166 |
| 51 | 124 | 0.344 |
| 52 | 613 | 1.699 |
| 53 | 31 | 0.086 |
| 54 | 82 | 0.227 |
| 55 | 7496 | 20.776 |
| 56 | 2373 | 6.577 |
| 57 | 1675 | 4.642 |
| 58 | 181 | 0.502 |
| 61 | 58 | 0.161 |
| 62 | 244 | 0.676 |
| 65 | 333 | 0.923 |
| 66 | 967 | 2.680 |
| 67 | 611 | 1.693 |
| 68 | 190 | 0.527 |
| 71 | 237 | 0.657 |
| 72 | 1061 | 2.941 |
| 73 | 36 | 0.100 |
| 74 | 23 | 0.064 |
| 75 | 2640 | 7.317 |
| 76 | 1447 | 4.011 |
| 77 | 8380 | 23.226 |
| 78 | 1416 | 3.925 |
| 81 | 34 | 0.094 |
| 82 | 346 | 0.959 |
| 83 | 14 | 0.039 |
| 85 | 50 | 0.139 |
| 86 | 106 | 0.294 |
| 87 | 565 | 1.566 |
| 88 | 2145 | 5.945 |

# 6.0 PRODUCTS

## 6.1 Census Tract Tabulations

A meaningful summary of Landsat land cover information for local agency use is by census tract. Early unavailability and later time and budget limitations prevented the use of 1980 census tract files. The 1980 tract boundaries were available at the completion of this project; and it is hoped that land cover summaries will be completed at some future date, with cooperative efforts from local governments. The 1970 census tract boundaries were available in image format for King County and Snohomish County. Work was concentrated on summarizing the 1979 local cover in the 1970 census tracts for King County.

### 6.1.1 Methodology

The 1970 census tracts were available in halfword image format with 60 meter pixels. Each census tract in the image had a unique density number, which could be related to its tract number through a centermatch file. The 1979 land cover image was overlayed on the 1970 census tract image using programs TIECONM and MGEOM in an image to image registration process. The census tract image was then overlayed on the land cover image using program POLYOVLY, and land cover tallies by census tract were output to an interface file. For King County, 1.2 million pixels were tallied into 247 census tracts. The eastern portion of the county, roughly corresponding to federal ownership was not included. IBIS programs

ROWOP, SORT, MF, AGGRG, TRANSCOL, ZIPCOL2 and REPORT, were used to manipulate the interface file to produce a report of land cover acreages and percentages by census tract. A census tract summary report is found in Appendix D.

### 6.1.2 Analysis

An analysis and comparison of the 1975 land cover tally and the 1979 land cover tally for the 1970 census tracts was undertaken. In a comparison, a number of differences between 1979 and 1975 were noted. It was anticipated that in addition to change, differences could be caused by factors such as differing analysis techniques, different software, analyst interpretation of land cover class definitions, analyst background and knowledge of the area, and stratification strategy.

Changes in the amount of urban land cover in King County Census tracts from 1975 to 1979 were analyzed by grouping the census tracts into City (Seattle), urbanized county, and rural county groups. The total acreage of urban land cover was summed for all tracts in each of the groups for 1975 and 1979. A base ratio of 1979/75 urbanized acreage ratio for each individual tract was compared to the base ratio for the overall group of tracts. Census tracts having the highest individual 1979/1975 ratio compared to their base ratio indicated where the most change had occurred.

The City of Seattle showed only small percentage change in a few census tracts which could have been caused by factors other than

actual change. The most significant increase in urban land cover occurred in tract 249, the Newport section of Bellevue. A large increase in commercial acreage occurred in the Kent Valley, notably in tracts 259, 283, and 292. Other areas showing signigicant gains in urban cover were tracts 219, 221, 222, 228 (Juanita-Redmond), 234 (Lake Hills), 255, 256, 257, 258, 259 (Renton), 294 (Kent), 305, 306, 307, 308, 309 (Auburn), 278, 287, 288, 289, 290 (Des Moines) and 300, 302, 303 (Federal Way).

## 6.2 Available Data at WSUCSC

Contact RSAL or WSU for tape volume information for the following data:

1. Interface file for 1970 census tracts and 1979 land cover in King County.
2. 71 spectral classes in unregistered format (HOM projection)
3. 34 land cover classes, UTM registered, square pixel (57 X 57 m) used for color display.
4. 34 land cover classes, UTM registered, rectangular pixel (76.2 m X 60,96 m), used for lineprinter output at 1:24,000 (8lpi X 10cpi)

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**Appendix A.**

PACIFIC NORTHWEST REGIONAL COMMISSION

LAND RESOURCES INVENTORY DEMONSTRATION PROJECT

# CENTRAL PUGET SOUND URBAN LAND INVENTORY

# DEMONSTRATION PLAN

User Agencies:
Washington State Office of Community Development
Puget Sound Council of Governments
Snohomish County Planning Department
King County Department of Budget & Program Planning
Pierce County Planning Department
Tacoma Planning Department
Thurston Regional Planning Council
Kitsap County
Mason Regional Planning Council
Jefferson-Port Townsend Regional Council

Additional Participant:

University of Washington
Remote Sensing Applications Laboratory

October 1976

## INTRODUCTION

Initial discussions with potential land resource management agencies in the Puget Sound region revealed a broad distribution of interests and information needs. These needs included land use classification (cover type), delimitation of urbanized areas, analysis of change at the urban fringe, identification of non-urban land within the urban area, location and measurement of disturbed land, input for river basin management modeling and examination of land/water surfaces. Further discussions have sifted this broad spectrum of issues and focused on the immediate need for a useable and repetetive system for obtaining land use data. State and local governments are faced with the growing issues of land use management. Federal statutes require better information; state requirements either already require better information or will in the near future; and there is a consensus that better, quicker, and more efficient ways of collecting basic land-use information must be developed.

Following is a descriptive outline of a cooperative demonstration between the National Aeronautics and Space Administration (NASA), U.S. Geological Survey (USGS), and a number of state, regional and local agencies in the State of Washington. This demonstration has the goal of exploring the technology of remote sensing and its potential as a source of needed planning information in the entire Puget Sound urban region.

## OBJECTIVE

The primary objective of this demonstration is to test the feasibility and cost-effectiveness of providing a wide variety of users with pertinent, timely,

land use information using remote sensing and computer-aided analysis of remote sensing data. A major component of the demonstration is the training of user personel in the analysis techniques necessary to extract useful information from multi-spectral data. Personnel from involved agencies are working with Landsat data and aerial imagery provided by NASA and USGS; training in data and equipment handling is provided at the installations of those two federal agencies and will enable users in the Puget Sound region to continue using Landsat and other data operationally after the completion of the project, should it prove feasible.

## STUDY AREA

The study area within Washington is approximately 8,000 square miles (22,000km$^2$) within a rectangle bounded by 48$^{\circ}$20' N, 123$^{\circ}$15' W, 46$^{\circ}$45' S, 121$^{\circ}$15' E.

This area includes all or portions of nine counties containing over sixty percent of the state's population as of April 1, 1975.

## USER EXPECTATIONS

### Washington State Office of Community Development (OCD)

OCD's primary interest is in the demonstrated production of useable land use data by remote sensing for three purposes:

1. Development of a statewide land use data system. The requirements of this system dictate that land use data be consistent statewide, representative of a cost-effective means of acquiring data, adaptable for

joining with other data and repeatable over time.

2. Assistance to local units of government in meeting their planning and resource management responsibilities by providing information and technical services. While recognizing the possibility of satisfying state information needs with general information, there is a commitment to meeting local information needs at the same time. This will require that OCD coordinate the various local users in order to develop the most effective and efficient demonstration project.
3. Inventory state renewable resources. As part of the statewide land use data system, OCD would like to use remotely sensed data to develop an inventory of agricultural, forest, and other open space lands. Such lands are currently gathering statewide attention in policy formulation at the state and local levels.

In addition to the actual production of data, OCD has a primary interest in exploring the possibility of developing an information system for managing this data and interacting with data from other sources. This activity will be emphasized during later phases of the demonstration (not covered by this plan).

Puget Sound Council of Governments (PSCOG)

PSCOG is updating the Regional Development Plan (RDP) for the Central Puget Sound Region. Three distinct uses of Landsat data are envisioned:

1. The primary use will be to provide a base for updating the land use component of the RDP from the existing data. The land use data should

conform to PSCOG's activity allocation model cells (based upon census tracts) for compatibility with current data and with current and proposed modeling efforts.

2. While the heavy burden for data rests with item (1), an equally important need is for graphic representation of the "urban form" of the region. This will be primarily used for public presentations and, especially, in discussions with local elected officials. It is particularly important to be able to communicate effectively and quickly with these officials who constitue the policy body of the Council.
3. PSCOG also expects Landsat data, in conjunction with conventional imagery, to provide information on ground cover for Section 208 (Federal Water Pollution Control Act) water quality management planning purposes, enabling the identification of areas with high surface water runoff potential, for example.

Snohomish County Planning Department

This county anticipates that the information derived from Landsat will be used in at least three ways:

1. The data will serve both as a primary base for natural system components and as a fine-screened data source for land use information. It will be used in automating the county's data base collecting and coding process. This data base provides the basic source of information for modeling and for the county's usual or special purpose planning program.

2. Provide an improved efficiency in correlating storm water runoff potential with the use of insecticides, fertilizers and clearing practices. The county is using computer models to conduct this analysis through its Water Quality Planning Program under Section 208 of the Water Pollution Control Act.
3. Finally, the county intends to use the information from Landsat in the land use planning implementation program. Eleven area comprehensive plans are currently maintained and require regular updating and amending. Current data is needed. Data is also required to prepare environmental impact statements or otherwise process permit applications and enforce the zoning ordinance. Demonstration data can fulfill some of the information needs for these programs.

King County

When it joined the demonstration, King County had three immediate uses for the Landsat data:

1. Incorporation into the existing information system. This is a manually-maintained series of overlays with forty variables relating to natural systems, transportation, demographic and economic factors. Specifically, the data would be used to update existing information (forest cover being one specific element). The system is the primary information tool for addressing a wide range of policy issues within the decision-making structure of the Department of Budget and Program Planning.

2. Updating existing land use data maintained on 1:24,000 scale maps derived from USGS quad sheets. This information would be shared with major suburban cities within the county for evaluation of land cover and urban area delimitation policies.
3. The major planning occurring within the county is in response to the Section 208 water quality management planning requirements. The current River Basin studies and modeling are integral parts of this effort. Statistical summaries of acreages by land cover type for drainage basins would provide a needed data element for both activities.

King County's present work program has de-emphasized the use of large-scale data in favor of community data for small area planning. Consequently, the county's participation in the demonstration has been reduced. It will, however, use what data and information are developed by the PSCOG for the area of King County.

Pierce County Planning Department

Pierce County has recently joined the demonstration project. Its expectations for the use of Landsat data are:

1. Production of uniform sets of data for the development of ecological plans. These plans require, among other things, a data inventory of natural science factors (e.g., geology, soils, hydrology, vegetation, etc.), socio-economic data, and land use data. The planners are seeking to relate data sets among the above factors in order to define and quantify relationships that would allow an evaluation of the effect of development on environmental quality.

2. Provide a commonly formated data base allowing interaction with the City of Tacoma's planning function. Landsat data will be used by both Tacoma and Pierce County.

City of Tacoma Planning Department

The City of Tacoma has also recently jointed the project. Four general uses of the Landsat data are expected:

1. Assisting in the verification of land use for Tacoma and Pierce County in conjunction with the Pierce County Planning Department.
2. Establish a Tacoma Land Use Data Base using remote sensing data from Landsat. This will include verification of land cover classifications related to detailed land use within the city.
3. Utilize remotely sensed data to monitor land use change.
4. Demonstrate the use of an interactive graphics terminal in displaying remotely sensed data in a local governmental environment.

This last interest relates to the efforts of Tacoma and the Jet Propulsion Laboratory (JPL) to transfer and demonstrate JPL's LUMIS/MILUS land information system to Tacoma (separate from the PNW Project demonstration).

Thurston Regional Planning Council (TRPC)

TRPC expects to obtain:

1. Land cover classification information relevant to a current program of developing comprehensive plans for sub-areas of the county. Land use

information is necessary to the program. The resource inventory capabilities of this data are of interest, specifically, examining the limits to obtaining the maximum amount of information possible for both human and natural systems.

2. The training of personnel will allow better evaluation of remote sensing products and methodology for its relevance and cost-effectiveness in meeting planning information needs. This will improve the agency's ability to use such information.

Kitsap County

Landsat data may help this county in the following ways:

1. Kitsap County, along with Jefferson and Mason Counties, is faced with planning for and managing the impact and growth generated by the siting of the Trident Submarine Support Facility in Kitsap County. Current planning strategy requires the ability to monitor growth and development over relatively short-time intervals. Landsat capability potentially offers a means for effectively and efficiently meeting this need.
2. Kitsap County also wishes to update its natural resource inventory and expects Landsat data to allow the determination of resource location at the census tract level of aggregation.

Mason Regional Planning Council

Mason County also faces the impact of the Trident Submarine Support Facility, located in Kitsap County. As with the previous user, the planning staff is limited

and stretched over a broad range of activities. Within the framework, two primary uses are anticipated for the data:

1. As a means to monitor rapid, Trident-related growth and development in the northeastern portion of the county.
2. For updating and refining the county land use map and establishing a baseline land use data file. This relates directly to the initial efforts to update the eight-year-old comprehensive plan.

Jefferson-Port Townsend Regional Council

Jefferson County and the City of Port Townsend, working together as a Regional Council, are initiating an accelerated planning program to respond to the expected impact of the Trident Submarine Support Facility. Here, as in the preceding cases, the ability to monitor change over a specific time interval is critical. The data will be used:

1. As a basic data input to developing (or updating) city, county, and regional comprehensive plans. This will include the Shoreline Master Programs for both the city and the county.
2. As a means for monitoring Trident-related growth.
3. As support for the implementation of new land development ordinances.
4. As an information base for making policy recommendations and decisions concerning specific development projects.

University of Washington

The Remote Sensing Applications Laboratory (RSAL), while not a user in the

normal sense, is an integral part of securing a fair test of the technology within the existing institutional framework with the State of Washington. RSAL will serve as a resource to demonstration users within the Central Puget Sound region, providing both equipment and technical assistance. It is expected that the demonstration study will allow the identification of useful additions to the inventory of hardware availble through RSAL.

OUTPUT PRODUCTS

All of the participating agencies will receive the following data products for the entire test area:

I. Preliminary Analysis - 1974 Landsat data
    1. Line-printer maps, 1:24,000 scale
    2. Color-coded map, 1:100,000 scale
II. Change - detection analysis, 1974-1975
III. Evaluation and documentation

In addition, each of the agencies will receive specific unique data products for the test area incompassing its political boundaries, for both 1974 and 1975 Landsat data. These unique data products are listed in Charts 1 and 2. The Office of Community Development (OCD) will receive duplicates of all of the unique data products.

The suggested classification categories for all users are listed below:

| LEVEL I | LEVEL II |
|---|---|
| Urban or Built-up | Clear Water |
| Agricultural | Sedimented Water |
| Forest | Wetlands |
| Water | Residential |
| Wetland | Cropland |
| Barren Land | Pasture/Grass Land |
| (Snow) | Conifer |
| | Dedidous |
| | Disturbed Land |
| | Bare Ground |
| | Commercial/Industrial |
| | Pavement |
| | Mobile Home Park |
| | Snow |
| | Regrowth |

## RESPONSIBILITIES

### NASA and USGS

NASA and USGS will have the primary responsibility for:

1. Providing satellite multi-spectral data and U-2 imagery.
2. Completion of digital processing of satellite data and providing training in digital analysis techniques.
3. Assistance in statistical design and analysis, and providing training in statistical methodology as appropriate.
4. Documentation of analysis techniques, demonstration results, and the costs associated with products.

User Agencies

The user agencies will assume the primary responsibility for:

1. Arranging for participation of their personnel to receive training in analysis techniques.
2. Providing ground truth for classification including identification of classifications and identification of test plots.
3. Use and evaluation of the products produced including an overall evaluation near the completion of the demonstration.

## PERSONNEL AND BUDGET ALLOCATIONS

The user agencies will provide the following resources in connection with this demonstration.

Office of Community Development

Up to one-half staff persons over the period covered by this plan. This will be provided by two persons from the Community Planning Division.

Puget Sound Council of Governments

Jefferson-Port Townsend

Three staff months over the period covered by the plan.

King County

Six staff months through September 1976.

Kitsap County

Mason County

Twenty percent of one staff person through the end of 1975. Future contribution to be determined.

Thurston County

Up to fifteen percent of one staff person over the period covered by the plan.

Snohomish County

Will support to the extent possible within the constraints of the Planning Department's yearly budget. This commitment will be further determined based upon 1) the long-term prospects of the system and 2) the implications of training staff for utilizing a technique without knowing the long-term functional potential within Washington State.

Pierce County

Tacoma

Remote Sensing Applications Laboratory (RSAL)

RSAL's commitment is in providing technical assistance and use of the resources of the laboratory. This includes use of the laboratory facilities (both interpreting equipment and access to imagery), as well as staff time of the following:

1. RSAL Director - 10%
2. Research Assistant/Professor - 20%
3. Research Assistant - 50%

## SCHEDULE

The Schedule for this demonstration is shown in Chart 3.

Chart 1 Unique Deliverable Products (By User Organization), Central Puget Sound Urban Land Inventory Demonstration, 1974 LANDSAT Data

| USER ORG. | LINE-PRINTER MAPS (1:24,000 Scale) | DICOMED PRINTS | DICOMED TRANSPARENCIES | TABULAR SUMMARIES | MAGNETIC TAPES |
|---|---|---|---|---|---|
| Kitsap County | County - 15 classes | County Grouped<br>1:63,000 Scale | | By County<br>By Planning Areas | |
| Mason County | County Planning Areas | County - 1:63,000 Scale | County - 8-1/2"x11"<br>Every cluster, grouped | By County<br>By Planning Area<br>Every cluster, grouped | |
| Jefferson County | County - Every cluster grouped | County Grouped<br>1:63,000 scale | Entire scene | By County<br>By Planning Areas<br>Grouped | |
| Pierce County | County Drainage Basins | County - Every cluster grouped<br>1:63,000 scale | | By County<br>By Drainage Basin<br>Every cluster | |
| PSCOG | Four Counties - Every cluster grouped (6 and 15 classes) | Four Counties at 1:100,000 and selected areas at 1:24,000 scale<br>Grouped (14-15 classes) | Four Counties Grouped (14-15 classes) | By County, River Basin,<br>AAM Eval. District,<br>AAM Super. Districts,<br>Districts, Census Tracts | Every cluster |
| Snohomish County | | | | | |
| Thurston County | County Grouped | County, 1:100,000 scale | County | By County<br>By Planning Area | |
| City of Tacoma | Tacoma - Pierce County<br>Every class<br>Planning Area Overlay | Tacoma - Pierce County<br>1:63,000 scale | | Grouped by Planning Areas | |

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Chart 2 - Unique Deliverable Products (By User Organization), Central Puget Sound Urban Land Inventory Demonstration, 1975 LANDSAT Data

| USER ORG. | LINE-PRINTER MAPS (1:24,000 Scale) | DICOMED PRINTS | DICOMED TRANSPARENCIES | TABULAR SUMMARIES | MAGNETIC TAPES |
|---|---|---|---|---|---|
| Kitsap County | County, all classes<br>County, changes | County<br>Grouped<br>1:63,000 Scale | Full scene | By County and Planning Areas, Grouped, and Changes, Same Boundaries | |
| Mason County | County, Planning Area<br>Every cluster and grouped | County<br>1:63,000 scale | County<br>8-1/2"x11"<br>Every cluster, grouped | By County<br>By Planning Areas<br>Every cluster, grouped | |
| Jefferson County | County<br>Grouped - Changes only | County<br>Grouped<br>1:63,000 scale | Entire scene | By County, By Planning Areas, Grouped<br>Changes by acreages and classification | |
| Pierce County | | | | | |
| PSCOG | Four Counties<br>Every Cluster<br>Grouped (6 and 15 classes) | Four Counties at 1:100,000 scale, and selected areas at 1:24,000 scale, Grouped (14-15 classes) | Four Counties Grouped (14-15 classes) | By County, River Basin, AAM Eval. District, AAM Super. Districts, Districts, Census Tracts | Every cluster |
| Snohomish County | | | | | |
| Thurston County | County<br>Grouped | | County | By County<br>By Planning Area<br>Changes From - To - | |
| City of Tacoma | Tacoma - Pierce County<br>Every Class | Tacoma - Pierce County<br>Every Class<br>1:63,000 scale | Tacoma - Pierce County<br>Every Class<br>1:63,000 scale | By Planning Area or by Census Tracts | By District<br>Every Class |

Chart 3 - Schedule for the Central Puget Sound Urban Land Inventory Demonstration

8/2/76

| TASK | 1976 | | | | | | | | | | | | 1977 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D |
| 1. Preliminary analysis, 1974 LANDSAT data. | | | | | | | | | | | | | | | | | | | | | | | | |
| 2. Agencies define product requirements. | | | | | | | | | | | | | | | | | | | | | | | | |
| 3. User workshops at ARC. | | | | | | | | | | | | | | | | | | | | | | | | |
| 4. Products based on 1974 LANDSAT data. | | | | | | | | | | | | | | | | | | | | | | | | |
| 5. Analysis based on 1975 LANDSAT data. | | | | | | | | | | | | | | | | | | | | | | | | |
| a. Acquire U-2 photo coverage. | | | | | | | | | | | | | | | | | | | | | | | | |
| b. Training site ground data delivered to ARC. | | | | | | | | △ | | | | | | | | | | | | | | | | |
| c. Cluster and classification analysis. | | | | | | | | | | | | | | | | | | | | | | | | |
| 6. Products based on 1975 LANDSAT data. | | | | | | | | | | | | | | | | | | | | | | | | |
| 7. Change detection analysis, 1974-1975. | | | | | | | | | | | | | | | | | | | | | | | | |
| 8. Evaluation and documentation. | | | | | | | | | | | | | | | | | | | | | | | | |

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**Appendix B. Participants in the LAP VICAR/IBIS Demonstration Project**

| Name | Agency | Address |
|---|---|---|
| Nancy Grabinski-Young | City of Tacoma<br>Planning Dept. | Medical Arts Bldg. 9th Floor<br>Tacoma, WA 98402 |
| Stearns Wood | City of Tacoma<br>Planning Dept. | Medical Arts Bldg. 9th Floor<br>Tacoma, WA 98402 |
| Chandler Felt | King County<br>Planning | W 217 King Co. Courthouse<br>Seattle, WA 98104 |
| Sharron Shinbo | King County<br>Planning | W 217 King Co. Courthouse<br>Seattle, WA 98104 |
| Charles Fulmer | King County<br>Planning | W 217 King Co. Courthouse<br>Seattle, WA 98104 |
| Don Pethick | Puget Sound Council<br>of Governments | 216 1st Ave. S.<br>Seattle, WA 98104 |
| Tom Byron | Puget Sound Council<br>of Governments | 216 1st Ave. S.<br>Seattle, WA 98104 |
| Jan Pilskog | Puget Sound Council<br>of Governments | 216 1st Ave. S.<br>Seattle, WA 98104 |
| Steve Cohn | City of Bellevue<br>Dept. of Planning | P.O. Box 1768<br>Bellevue, WA 98009 |
| Caroline Berry | City of Bellevue<br>Dept. of Planning | P.O. Box 1768<br>Bellevue, WA 98009 |
| Sheila Moss | City of Bellevue<br>Dept. of Planning | P.O. Box 1768<br>Bellevue, WA 98009 |
| Matt Clark | Snohomish County<br>Planning | 5th Floor County Admin. Bldg.<br>Everett, WA 98201 |
| Penny Biddlecome | Snohomish County<br>Planning | 5th Floor County Admin. Bldg.<br>Everett, WA 98201 |
| Denise Lello | Snohomish County<br>Planning | 5th Floor County Admin. Bldg.<br>Everett, WA 98201 |
| Tom Weber | Kitsap County<br>Community Development | 614 Division St.<br>Port Orchard, WA 98366 |
| Pete Swennson | Thurston Reg. Planning<br>Council | Building #1 2000 Lakeside Drive SW<br>Olympia, WA 98502 |
| Robert Thompson | Thurston Reg. Planning<br>Council | Building #1 2000 Lakeside Drive SW<br>Olympia, WA 98502 |
| Timothy Koss | Mason Regional Planning | P.O. Box 186<br>Shelton, WA 98584 |
| Tim Fitzthum | Mason Regional Planning | P.O. Box 186<br>Shelton, WA 98584 |
| Larry Brewer | Wash. Dept. of Game | P.O. Box 412<br>Mt. Vernon, WA 98273 |
| Ken Langram | Western Washington Univ. | Dept. of Geography<br>Bellingham, WA 98225 |
| Robert Scott | Wash. Dept. of Natural<br>Resources | Resource Inventory Section<br>Olympia, WA 98504 |
| Tim Gregg | Wash. Dept. of Natural<br>Resources | Resource Inventory Section<br>Olympia, WA 98504 |
| Eric Barthmaier | Wash. Dept. of Natural<br>Resources | Resource Inventory Section<br>Olympia, WA 98504 |
| Ron Effland | Wash. Dept. of Ecology | Mail Stop PV-11<br>Olympia, WA 98504 |
| Jeff Finn | Seattle Dept. of Community<br>Development | 400 Yesler Bldg. 2nd Floor<br>Seattle, WA 98102 |
| Rob Odle | Kirkland Dept. of<br>Community Development | 210 Main ST.<br>Kirkland, WA 98033 |
| Carl Youngman | Dept. of Geography | Univ. of Washington<br>Seattle, WA 98195 |
| Steve Tanimoto | Dept. of Computer Science | Univ. of Washington<br>Seattle, WA 98195 |

## Appendix C. VICAR/IBIS Jobs Requested by Participants in the LAP VICAR/IBIS Demonstration Project

VICAR/IBIS Jobs requested by participants

1. Lineprinter map output (Program Display)

| Map Area | Participant/Agency | Study Purpose |
|---|---|---|
| Tulalip Indian Reservation | Larry Brewer/Wash. Dept. of Game | Forest grouse habitat |
| Snohomish Co. | Matt Clark/Snohomish Co. Planning | Baseline data for agricultural change study |
| Bellevue | Sheila Moss, Caroline Berry/ Bellevue Planning | Assess Landsat for vacant lands location |
| Redmond/Kirkland/ Bellevue | Rob Odle/City of Kirkland<br>Steve Cohn/Bellevue Planning<br>Chandler Felt/ King Co. Planning | Assess vacant lands and test verif- ication routine |
| Kirkland | Rob Odle/City of Kirkland | Pervious surfaces location |
| Mima Prairie, Thurston Co. | Pete Swennson/Thurston Co. Planning | Assess Landsat spectral cluster accuracy for grasslands |
| Western Skagit Co. | Ken Langran/Western Washington Univ. | Demonstrate general land cover |
| Hood Canal & SW Kitsap Peninsula | Tim Koss/Mason Co. Planning | General land cover location |
| Seattle | Jeff Finn/Seattle Dept. of Community Development | General land cover for use in color display experiment |
| Bellingham & Western Whatcom Co. | Ken Langran/Western Washington Univ. | Graphics technique in Landsat land cover maps |
| Seattle | All agencies | Demonstrate mapping of census tract boundaries |

2. Report Output from IBIS Interface files (Program Report)

| Report Subject | Participants |
|---|---|
| Agricultural land tally by census tract for Snohomish Co. | Matt Clark/Snohomish Co. Planning |
| General land cover tally by census tract for central Puget Sound | All agencies |

3. Histograms and Frequency Distribution (Program List)

| Area | Participants |
|---|---|
| Redmond/Kirkland/Bellevue | Rob Odle/City of Kirkland<br>Steve Cohn/Bellevue Planning<br>Chandler Felt/King Co. Planning |
| Bellingham | Ken Langran/Western Washington Univ. |

# APPENDIX D: King County Census Tract Summary

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18140
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSC

| CENSUS TRACT NUMBER | RESIDENTIAL | | WOODED RESIDENTIAL | | COMMERCIAL, INDUSTRIAL | | OPEN WATER | | WETLAND | | BARE GROUND | | GRASS, PASTURE | | SHADOW, UNCLASSED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| 1 | 223 | 52.77 | 36 | 8.43 | 87 | 20.32 | 0 | 0.0 | 0 | 0.0 | 1 | 0.22 | 25 | 5.99 | 4 | 0.89 |
| 2 | 478 | 57.10 | 64 | 7.60 | 79 | 9.39 | 0 | 0.0 | 0 | 0.0 | 1 | 0.11 | 53 | 6.37 | 13 | 1.55 |
| 3 | 218 | 72.81 | 29 | 9.65 | 31 | 10.31 | 0 | 0.0 | 0 | 0.0 | 2 | 0.63 | 3 | 0.94 | 3 | 0.95 |
| 4 | 486 | 66.37 | 22 | 2.94 | 104 | 14.19 | 13 | 1.79 | 0 | 0.0 | 26 | 3.58 | 12 | 1.65 | 13 | 1.79 |
| 5 | 254 | 37.02 | 80 | 11.61 | 1 | 0.14 | 14 | 2.05 | 0 | 0.0 | 9 | 1.37 | 7 | 0.96 | 19 | 2.73 |
| 6 | 522 | 54.12 | 83 | 8.63 | 168 | 17.36 | 14 | 1.45 | 0 | 0.0 | 31 | 3.20 | 32 | 3.30 | 11 | 1.15 |
| 7 | 201 | 63.99 | 26 | 8.33 | 73 | 23.21 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.30 | 2 | 0.50 |
| 8 | 242 | 80.44 | 23 | 7.76 | 16 | 5.28 | 0 | 0.0 | 0 | 0.0 | 4 | 1.24 | 0 | 0.0 | 4 | 1.29 |
| 9 | 135 | 60.25 | 37 | 16.74 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 3.77 | 4 | 1.57 |
| 10 | 152 | 65.85 | 33 | 14.23 | 17 | 7.32 | 0 | 0.0 | 0 | 0.0 | 4 | 1.61 | 2 | 0.81 | 1 | 0.51 |
| 11 | 147 | 62.06 | 48 | 20.16 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.40 | 5 | 1.99 |
| 12 | 228 | 46.39 | 12 | 2.47 | 202 | 41.06 | 0 | 0.0 | 0 | 0.0 | 9 | 1.90 | 3 | 0.57 | 4 | 0.76 |
| 13 | 174 | 60.98 | 7 | 2.62 | 81 | 28.52 | 0 | 0.0 | 0 | 0.0 | 7 | 2.30 | 6 | 1.97 | 2 | 0.55 |
| 14 | 329 | 84.40 | 16 | 3.12 | 30 | 5.87 | 0 | 0.0 | 0 | 0.0 | 2 | 0.37 | 5 | 0.97 | 4 | 0.73 |
| 15 | 168 | 60.07 | 45 | 16.11 | 5 | 1.68 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 1.01 |
| 16 | 317 | 68.62 | 48 | 10.32 | 41 | 8.91 | 0 | 0.0 | 0 | 0.0 | 7 | 1.62 | 1 | 0.20 | 11 | 2.43 |
| 17 | 453 | 84.76 | 1 | 0.18 | 77 | 14.36 | 0 | 0.0 | 0 | 0.0 | 3 | 0.53 | 0 | 0.0 | 1 | 0.18 |
| 18 | 165 | 77.13 | 0 | 0.0 | 49 | 21.21 | 0 | 0.0 | 0 | 0.0 | 11 | 4.92 | 0 | 0.0 | 4 | 1.65 |
| 19 | 296 | 71.33 | 3 | 0.68 | 90 | 21.67 | 0 | 0.0 | 0 | 0.0 | 7 | 1.81 | 2 | 0.45 | 4 | 0.90 |
| 20 | 205 | 78.49 | 27 | 10.39 | 10 | 3.94 | 5 | 1.79 | 0 | 0.0 | 3 | 1.08 | 0 | 0.0 | 5 | 1.79 |
| 21 | 218 | 66.38 | 61 | 18.52 | 15 | 4.56 | 0 | 0.0 | 0 | 0.0 | 4 | 1.16 | 3 | 0.85 | 3 | 0.85 |
| 22 | 495 | 60.11 | 66 | 7.95 | 23 | 2.84 | 0 | 0.0 | 0 | 0.0 | 4 | 0.45 | 102 | 12.39 | 4 | 0.45 |
| 23 | 141 | 31.46 | 6 | 1.25 | 145 | 32.29 | 0 | 0.0 | 0 | 0.0 | 93 | 20.63 | 11 | 2.50 | 11 | 2.50 |
| 24 | 215 | 83.33 | 3 | 1.09 | 22 | 8.70 | 0 | 0.0 | 0 | 0.0 | 7 | 2.54 | 0 | 0.0 | 7 | 2.54 |
| 25 | 128 | 85.09 | 0 | 0.0 | 5 | 3.11 | 0 | 0.0 | 0 | 0.0 | 3 | 1.86 | 9 | 6.21 | 0 | 0.0 |
| 26 | 243 | 75.80 | 0 | 0.0 | 62 | 19.24 | 3 | 0.87 | 0 | 0.0 | 3 | 0.87 | 0 | 0.0 | 7 | 2.06 |
| 27 | 314 | 73.04 | 4 | 0.87 | 93 | 21.52 | 6 | 1.30 | 0 | 0.0 | 1 | 0.22 | 0 | 0.0 | 3 | 0.55 |
| 28 | 204 | 90.83 | 0 | 0.0 | 21 | 9.17 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 29 | 221 | 82.23 | 0 | 0.0 | 47 | 17.42 | 0 | 0.0 | 0 | 0.0 | 1 | 0.35 | 0 | 0.0 | 0 | 0.0 |
| 30 | 335 | 90.40 | 1 | 0.25 | 33 | 8.84 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.51 |
| 31 | 411 | 77.15 | 10 | 1.93 | 43 | 8.08 | 7 | 1.41 | 0 | 0.0 | 3 | 0.53 | 0 | 0.0 | 4 | 0.70 |
| 32 | 375 | 56.16 | 7 | 0.98 | 184 | 27.59 | 51 | 7.70 | 0 | 0.0 | 1 | 0.16 | 3 | 0.42 | 42 | 6.30 |
| 33 | 226 | 71.94 | 0 | 0.0 | 80 | 25.67 | 0 | 0.0 | 0 | 0.0 | 5 | 1.49 | 0 | 0.0 | 3 | 0.90 |
| 34 | 160 | 78.45 | 0 | 0.0 | 42 | 20.64 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.92 |
| 35 | 235 | 74.93 | 22 | 6.87 | 40 | 12.84 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | 1.19 | 3 | 0.90 |
| 36 | 206 | 67.49 | 0 | 0.0 | 95 | 31.29 | 1 | 0.31 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 0.51 |
| 37 | 65 | 83.13 | 1 | 1.20 | 11 | 14.46 | 0 | 0.0 | 0 | 0.0 | 1 | 1.20 | 0 | 0.0 | 0 | 0.0 |
| 38 | 162 | 91.02 | 3 | 1.80 | 9 | 5.99 | 0 | 0.0 | 0 | 0.0 | 1 | 0.60 | 1 | 0.60 | 0 | 0.0 |
| 39 | 326 | 91.57 | 0 | 0.0 | 7 | 2.68 | 0 | 0.0 | 0 | 0.0 | 5 | 1.92 | 4 | 1.53 | 2 | 0.77 |
| 40 | 162 | 90.58 | 3 | 1.57 | 7 | 3.66 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 1.05 | 0 | 0.0 |
| 41 | 484 | 59.36 | 97 | 11.94 | 22 | 2.64 | 64 | 7.81 | 0 | 0.0 | 2 | 0.23 | 50 | 6.09 | 26 | 3.71 |
| 42 | 512 | 78.16 | 19 | 2.86 | 55 | 8.43 | 0 | 0.0 | 0 | 0.0 | 10 | 1.57 | 19 | 2.86 | 1 | 0.16 |
| 43 | 166 | 73.80 | 17 | 7.57 | 49 | 21.25 | 0 | 0.0 | 0 | 0.0 | 3 | 1.52 | 3 | 1.52 | 1 | 0.30 |
| 44 | 151 | 57.50 | 5 | 1.78 | 82 | 31.52 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 4 | [illegible] | 1 | 0.35 |
| 45 | 138 | 80.33 | 0 | 0.0 | 33 | 19.13 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.53 |
| 46 | 203 | [illegible] | 24 | 8.02 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 47 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 48 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 49 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 50 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 52 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 53 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 54 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 55 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 56 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 57 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 58 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 59 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 60 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 61 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 63 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 64 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 65 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 66 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 67 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 68 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 69 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 70 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 71 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 72 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 73 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 74 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 75 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 76 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 77 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 78 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 79 | 120 | 71.51 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 80 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 81 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 82 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 83 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 84 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 85 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 86 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 87 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 88 | 196 | 81.96 | 0 | 0.0 | [illegible] | [illegible] | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

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OF POOR QUALITY

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18140
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSC

| CENSUS TRACT NUMBER | CROPLAND | | BRUSH (DRY) | | TALL SHRUB | | DECIDUOUS FOREST | | MIXED FOREST | | CONIFEROUS FOREST | | OLD CONIFER FOREST | | REGROWTH FOREST | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| 1 | 0 | 0.0 | 2 | 0.44 | 7 | 1.55 | 9 | 2.22 | 27 | 6.43 | 2 | 0.44 | 0 | 0.0 | 0 | 0.0 |
| 2 | 0 | 0.0 | 69 | 8.27 | 27 | 3.24 | 3 | 0.36 | 42 | 5.03 | 7 | 0.78 | 0 | 0.0 | 0 | 0.0 |
| 3 | 0 | 0.0 | 7 | 2.19 | 0 | 0.0 | 0 | 0.0 | 7 | 2.50 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 4 | 0 | 0.0 | 25 | 3.45 | 14 | 1.92 | 0 | 0.0 | 17 | 2.30 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 5 | 0 | 0.0 | 37 | 2.33 | 0 | 0.0 | 15 | 2.32 | 37 | 8.33 | 161 | 23.50 | 1 | 1.64 | 0 | 0.0 |
| 6 | 0 | 0.0 | 20 | 2.06 | 18 | 1.65 | 2 | 0.16 | 56 | 5.82 | 9 | 0.97 | 1 | 0.10 | 0 | 0.0 |
| 7 | 0 | 0.0 | 3 | 0.89 | 0 | 0.0 | 0 | 0.0 | 7 | 2.08 | 2 | 0.60 | 0 | 0.0 | 0 | 0.0 |
| 8 | 0 | 0.0 | 7 | 2.17 | 1 | 0.31 | 0 | 0.0 | 4 | 1.24 | 1 | 0.31 | 0 | 0.0 | 0 | 0.0 |
| 9 | 0 | 0.0 | 16 | 7.11 | 7 | 2.93 | 1 | 0.42 | 16 | 7.11 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 10 | 0 | 0.0 | 3 | 1.22 | 5 | 2.03 | 2 | 0.81 | 12 | 5.28 | 1 | 0.41 | 0 | 0.0 | 0 | 0.0 |
| 11 | 0 | 0.0 | 7 | 3.16 | 1 | 0.40 | 13 | 5.51 | 15 | 6.32 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 12 | 0 | 0.0 | 6 | 1.14 | 4 | 0.76 | 0 | 0.0 | 26 | 4.94 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 13 | 0 | 0.0 | 0 | 0.0 | 1 | 0.35 | 2 | 0.66 | 6 | 1.97 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 14 | 0 | 0.0 | 1 | 0.18 | 0 | 0.0 | 29 | 5.09 | 66 | 11.86 | 30 | 5.87 | 0 | 0.0 | 0 | 0.0 |
| 15 | 0 | 0.0 | 8 | 3.02 | 1 | 0.34 | 2 | 0.67 | 29 | 10.40 | 19 | 6.71 | 0 | 0.0 | 0 | 0.0 |
| 16 | 0 | 0.0 | 2 | 0.40 | 1 | 0.20 | 3 | 0.61 | 21 | 4.45 | 10 | 2.23 | 0 | 0.0 | 0 | 0.0 |
| 17 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 18 | 0 | 0.0 | 3 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 19 | 0 | 0.0 | 0 | 0.0 | 7 | 1.81 | 0 | 0.0 | 6 | 1.35 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 20 | 0 | 0.0 | 3 | 1.08 | 1 | 0.36 | 0 | 0.0 | 3 | 1.08 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 21 | 0 | 0.0 | 12 | 3.70 | 1 | 0.28 | 0 | 0.0 | 12 | 3.70 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 22 | 0 | 0.0 | 6 | 0.68 | 20 | 2.34 | 16 | 1.93 | 71 | 8.64 | 18 | 2.16 | 0 | 0.0 | 0 | 0.0 |
| 23 | 0 | 0.0 | 2 | 0.47 | 22 | 5.00 | 0 | 0.0 | 18 | 3.96 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 24 | 0 | 0.0 | 5 | 1.81 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 25 | 0 | 0.0 | 0 | 0.0 | 5 | 3.11 | 0 | 0.0 | 1 | 0.62 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 26 | 0 | 0.0 | 1 | 0.29 | 3 | 0.87 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 27 | 0 | 0.0 | 4 | 2.17 | 1 | 0.22 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 28 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 29 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 30 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 31 | 0 | 0.0 | 6 | 1.05 | 0 | 0.0 | 3 | 0.53 | 4 | 0.70 | 42 | 7.91 | 0 | 0.0 | 0 | 0.0 |
| 32 | 0 | 0.0 | 0 | 0.0 | 1 | 0.14 | 0 | 0.0 | 2 | 0.28 | 2 | 0.28 | 0 | 0.0 | 0 | 0.0 |
| 33 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 34 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 35 | 0 | 0.0 | 0 | 0.0 | 2 | 0.60 | 0 | 0.0 | 8 | 2.69 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 36 | 0 | 0.0 | 0 | 0.0 | 1 | 0.31 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 37 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 38 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 39 | 0 | 0.0 | 1 | 0.38 | 2 | 0.77 | 0 | 0.0 | 1 | 0.38 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 40 | 0 | 0.0 | 0 | 0.0 | 3 | 1.05 | 0 | 0.0 | 6 | 2.09 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 41 | 0 | 0.0 | 22 | 2.64 | 3 | 0.36 | 9 | 1.15 | 36 | 4.56 | 2 | 0.23 | 0 | 0.0 | 0 | 0.0 |
| 42 | 0 | 0.0 | 0 | 0.0 | 15 | 2.29 | 7 | 1.02 | 18 | 2.71 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 43 | 0 | 0.0 | 4 | 1.22 | 10 | 3.16 | 7 | 2.43 | 26 | 7.90 | 4 | 1.22 | 0 | 0.0 | 0 | 0.0 |
| 44 | 0 | 0.0 | 3 | 1.07 | 0 | 0.0 | 6 | 2.14 | 7 | 2.85 | 5 | 1.78 | 0 | 0.0 | 0 | 0.0 |
| 45 | [illegible] | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 46 | 0 | 0.0 | 2 | 0.62 | 10 | 3.40 | 1 | 0.31 | 26 | 8.02 | 2 | 0.62 | 0 | 0.0 | 0 | 0.0 |
| 47 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 48 | 0 | 0.0 | 1 | 0.27 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 49 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 50 | 0 | 0.0 | 0 | 0.0 | 3 | 1.53 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 51 | 0 | 0.0 | 0 | 0.0 | 2 | 0.92 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 52 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 53 | 0 | 0.0 | 15 | 2.02 | 11 | 1.51 | 4 | 0.50 | 27 | 3.66 | 1 | 0.13 | 1 | 0.15 | 0 | 0.0 |
| 54 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 55 | 6 | 0.80 | 15 | 2.16 | 56 | 7.77 | 86 | 12.33 | 93 | 13.27 | 28 | 4.02 | 0 | 0.0 | 0 | 0.0 |
| 56 | 0 | 0.0 | 12 | 1.59 | 10 | 1.30 | 12 | 1.74 | 52 | 6.63 | 20 | 2.57 | 0 | 0.0 | 0 | 0.0 |
| 57 | 0 | 0.0 | 6 | 0.97 | 9 | 1.62 | 10 | 1.78 | 37 | 6.32 | 15 | 3.27 | 0 | 0.0 | 0 | 0.0 |
| 58 | 0 | 0.0 | 1 | 0.08 | 43 | 3.65 | 10 | 0.87 | 27 | 2.30 | 1 | 0.08 | 0 | 0.0 | 0 | 0.0 |
| 59 | 0 | 0.0 | 2 | 0.41 | 9 | 2.06 | 0 | 0.0 | 2 | 0.41 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 60 | 0 | 0.0 | 5 | 1.13 | 2 | 0.57 | 0 | 0.0 | 19 | 5.67 | 3 | 0.85 | 0 | 0.0 | 0 | 0.0 |
| 61 | 0 | 0.0 | 7 | 1.89 | 2 | 0.54 | 0 | 0.0 | 7 | 2.16 | 2 | 0.54 | 0 | 0.0 | 0 | 0.0 |
| 62 | 0 | 0.0 | 21 | 3.02 | 10 | 1.51 | 32 | 4.66 | 103 | 15.07 | 50 | 7.27 | 1 | 0.16 | 0 | 0.0 |
| 63 | 0 | 0.0 | 16 | 2.12 | 0 | 0.0 | 25 | 3.82 | 59 | 8.91 | 20 | 2.97 | 0 | 0.0 | 0 | 0.0 |
| 64 | 0 | 0.0 | 26 | 11.07 | 2 | 0.79 | 2 | 0.79 | 3 | 1.19 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 65 | 0 | 0.0 | 44 | 14.29 | 3 | 0.91 | 5 | 1.52 | 22 | 7.29 | 7 | 2.13 | 0 | 0.0 | 0 | 0.0 |
| 66 | 0 | 0.0 | 6 | 2.76 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 15 | 4.91 | 0 | 0.0 | 0 | 0.0 |
| 67 | 0 | 0.0 | 1 | 0.28 | 9 | 2.75 | 3 | 0.83 | 6 | 1.65 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 68 | 0 | 0.0 | 0 | 0.0 | 1 | 0.33 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 69 | 0 | 0.0 | 6 | 1.54 | 3 | 0.77 | 5 | 1.16 | 5 | 1.16 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 70 | 0 | 0.0 | 2 | 0.95 | 0 | 0.0 | 0 | 0.0 | 2 | 0.95 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 71 | 0 | 0.0 | 1 | 0.38 | 0 | 0.0 | 0 | 0.0 | 2 | 0.77 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 72 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 0.36 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 73 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 74 | 0 | 0.0 | 1 | 0.65 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 75 | 0 | 0.0 | 2 | 0.90 | 1 | 0.45 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 76 | 0 | 0.0 | 1 | 0.64 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 77 | 0 | 0.0 | 0 | 0.0 | 8 | 3.15 | 0 | 0.0 | 7 | 2.65 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 78 | 0 | 0.0 | 8 | 1.37 | 9 | 1.07 | 26 | 3.97 | 65 | 10.53 | 8 | 1.55 | 0 | 0.0 | 0 | 0.0 |
| 79 | 0 | 0.0 | 4 | 2.25 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 80 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 81 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 82 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 83 | 0 | 0.0 | 1 | 1.27 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 84 | 0 | 0.0 | 1 | 1.02 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 85 | 0 | 0.0 | 0 | 0.0 | 1 | 0.74 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 86 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 87 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 88 | 0 | 0.0 | 0 | 0.0 | 3 | 1.18 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |

ORIGINAL PAGE IS
OF POOR QUALITY

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18140
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSC

| CENSUS TRACT NUMBER | RESIDENTIAL | | WOODED RESIDENTIAL | | COMMERCIAL, INDUSTRIAL | | OPEN WATER | | WETLAND | | BARE GROUND | | GRASS, PASTURE | | SHADOW, UNCLASSED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18150
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSC

| CENSUS TRACT NUMBER | CROPLAND | | BRUSH (DRY) | | TALL SHRUB | | DECIDUOUS FOREST | | MIXED FOREST | | CONIFEROUS FOREST | | OLD CONIFER FOREST | | REGROWTH FOREST | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| 89 | 0 | 0.0 | 1 | 0.26 | 8 | 2.36 | 10 | 2.84 | 15 | 4.19 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18140
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSF

| CENSUS TRACT NUMBER | RESIDENTIAL | | WOODED RESIDENTIAL | | COMMERCIAL, INDUSTRIAL | | OPEN WATER | | WETLAND | | BARE GROUND | | GRASS, PASTURE | | SHADOW, UNCLASSED | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| 256 | 205 | 10.28 | 344 | 17.23 | 108 | 5.40 | 0 | 0.0 | 7 | 0.33 | 97 | 4.88 | 177 | 8.87 | 20 | 0.99 |
| 257 | 320 | 18.51 | 248 | 14.34 | 74 | 4.27 | 0 | 0.0 | 10 | 0.60 | 93 | 5.47 | 202 | 11.69 | 27 | 1.57 |
| 258 | 527 | 23.52 | 385 | 17.03 | 75 | 3.31 | 0 | 0.0 | 7 | 0.31 | 389 | [illegible] | 211 | 9.44 | 24 | 1.08 |
| 259 | 423 | 19.52 | 29 | 1.34 | 374 | 17.27 | 0 | 0.0 | 34 | 1.54 | 298 | 13.55 | 505 | 22.87 | 28 | 1.30 |
| 260 | 809 | 59.92 | 35 | 2.57 | 81 | 6.03 | 0 | 0.0 | 0 | 0.0 | 40 | 2.98 | 113 | 8.39 | 13 | 0.97 |
| 261 | 620 | 57.72 | 48 | 4.45 | 71 | 6.63 | 0 | 0.0 | 0 | 0.0 | 24 | 2.27 | 81 | 7.59 | 13 | 1.22 |
| 262 | 583 | 31.85 | 25 | 1.38 | 635 | 34.66 | 10 | 0.56 | 63 | 3.41 | 94 | 5.11 | 113 | 6.19 | 38 | 2.10 |
| 263 | 338 | 25.68 | 17 | 1.28 | 727 | 54.84 | 21 | 1.56 | 0 | 0.0 | 62 | 4.60 | 42 | 3.20 | 22 | [illegible] |
| 264 | 488 | 43.34 | 22 | 1.91 | 204 | 18.14 | 23 | 2.00 | 0 | 0.0 | 23 | 2.04 | 155 | 13.76 | 26 | [illegible] |
| 265 | 198 | 67.52 | 5 | 1.59 | 25 | 8.60 | 0 | 0.0 | 0 | 0.0 | 12 | 4.28 | 15 | 5.10 | 3 | [illegible] |
| 266 | 209 | 79.08 | 5 | 1.77 | 21 | 7.80 | 0 | 0.0 | 0 | 0.0 | 4 | 1.47 | 9 | 3.58 | 0 | 0.0 |
| 267 | 430 | 58.25 | 56 | 7.61 | 33 | 4.44 | 13 | 1.78 | 0 | 0.0 | 5 | 0.62 | 10 | 1.40 | 8 | [illegible] |
| 268 | 739 | 80.10 | 10 | 1.12 | 88 | 9.54 | 0 | 0.0 | 0 | 0.0 | 22 | 2.34 | 8 | 0.91 | 20 | [illegible] |
| 269 | 162 | 89.64 | 1 | 0.52 | 8 | 4.66 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | 0 | 0.0 | [illegible] | [illegible] |
| 270 | 423 | 81.44 | 25 | 4.86 | 9 | 1.80 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 271 | 250 | 62.53 | 4 | 0.94 | 12 | 3.04 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 272 | 365 | 45.72 | 2 | 0.23 | 171 | 21.45 | 0 | 0.0 | 0 | 0.0 | 41 | 5.16 | 90 | 11.25 | [illegible] | [illegible] |
| 273 | 658 | 72.62 | 12 | 1.34 | 60 | 6.61 | 1 | 0.10 | 0 | 0.0 | 39 | 4.34 | 30 | 3.31 | 10 | [illegible] |
| 274 | 598 | 71.56 | 40 | 4.82 | 72 | 8.62 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 275 | 460 | 78.31 | 5 | 0.80 | 101 | 17.22 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 276 | 244 | 35.80 | 55 | 8.09 | 26 | 3.84 | 7 | 1.10 | 0 | 0.0 | 8 | [illegible] | 5 | [illegible] | 25 | 3.70 |
| 277 | 212 | 0.89 | 719 | 3.02 | 126 | 0.53 | 745 | 3.13 | 236 | 0.99 | 114 | 0.48 | 3871 | 16.29 | 312 | 1.31 |
| 278 | 293 | 41.68 | 115 | 16.38 | 17 | 2.40 | 4 | 0.53 | 0 | 0.0 | 3 | 0.40 | 11 | 1.60 | [illegible] | [illegible] |
| 279 | 486 | 55.04 | 45 | 5.09 | 217 | 24.60 | 33 | 3.71 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 280 | 303 | 60.79 | 23 | 4.32 | 88 | 17.64 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 281 | 265 | 40.78 | 5 | 0.72 | 234 | 36.02 | 0 | 0.0 | 0 | 0.0 | 38 | 5.91 | 30 | 4.61 | [illegible] | [illegible] |
| 282 | 300 | 47.77 | 14 | 2.23 | 48 | 7.59 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 283 | 394 | 17.74 | 67 | 3.03 | 225 | 10.11 | 0 | 0.0 | 13 | [illegible] | [illegible] | [illegible] | 106 | [illegible] | [illegible] | [illegible] |
| 284 | 841 | 39.38 | 33 | 1.53 | 880 | 41.17 | 7 | 0.31 | [illegible] | [illegible] | [illegible] | [illegible] | 665 | 29.92 | [illegible] | [illegible] |
| 285 | 489 | 47.58 | 72 | 7.02 | 118 | 11.49 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 286 | 643 | 39.48 | 309 | 18.97 | 44 | 2.70 | 5 | 0.29 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 287 | 293 | 44.02 | 162 | 24.33 | 4 | 0.56 | 1 | 0.14 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 288 | 392 | 19.07 | 409 | 19.89 | 197 | 9.60 | 97 | 4.73 | 14 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 289 | 283 | 24.43 | 265 | 22.90 | 145 | 12.54 | 2 | 0.16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 290 | 350 | 19.56 | 300 | 16.79 | 169 | 9.47 | 3 | 0.16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 291 | 318 | 19.26 | 197 | 11.90 | 74 | 4.48 | 3 | 0.17 | [illegible] | [illegible] | 125 | [illegible] | 353 | [illegible] | [illegible] | [illegible] |
| 292 | 911 | 13.91 | 320 | 4.89 | 1094 | 16.71 | 11 | 0.17 | 100 | [illegible] | 489 | [illegible] | 1651 | [illegible] | [illegible] | [illegible] |
| 293 | 374 | 8.73 | 631 | 14.72 | 51 | 1.18 | 13 | 0.31 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 294 | 340 | 13.73 | 271 | 10.97 | 89 | 3.59 | 0 | 0.0 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 295 | 165 | 8.00 | 288 | 13.92 | 77 | 3.71 | 5 | 0.23 | 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 296 | 80 | 3.03 | 227 | 8.62 | 10 | 0.39 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 297 | 284 | 11.44 | 308 | 12.42 | 132 | 5.32 | 0 | 0.0 | 20 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 298 | 409 | 10.96 | 381 | 10.21 | 38 | 1.03 | 33 | 0.89 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 299 | 155 | 5.56 | 295 | 10.56 | 43 | 1.54 | 12 | 0.44 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 300 | 453 | 16.17 | 497 | 17.74 | 187 | 6.68 | 39 | 1.40 | 96 | [illegible] | 126 | [illegible] | 183 | [illegible] | 37 | [illegible] |
| 301 | 197 | 14.20 | 345 | 24.95 | 22 | 1.62 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 302 | 380 | 25.52 | 322 | 21.62 | 97 | 6.54 | 16 | 1.07 | [illegible] | [illegible] | [illegible] | [illegible] | 80 | [illegible] | [illegible] | [illegible] |
| 303 | 1032 | 12.95 | 1062 | 13.32 | 513 | 6.43 | 12 | 0.15 | [illegible] | [illegible] | 400 | 5.01 | 626 | 7.85 | [illegible] | [illegible] |
| 304 | 202 | 3.47 | 505 | 8.65 | 77 | 1.32 | 121 | 2.07 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 139 | [illegible] |
| 305 | 636 | 15.94 | 327 | 8.18 | 427 | 10.69 | 2 | 0.05 | [illegible] | [illegible] | 207 | [illegible] | 1517 | 37.98 | [illegible] | [illegible] |
| 306 | 295 | 33.33 | 164 | 18.52 | 55 | 6.24 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | 87 | [illegible] | [illegible] | [illegible] |
| 307 | 162 | 44.70 | 66 | 18.35 | 66 | 18.09 | 0 | 0.3 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 308 | 524 | 24.28 | 279 | 12.92 | 617 | 28.58 | 0 | 0.0 | 60 | [illegible] | [illegible] | [illegible] | 230 | 10.67 | 25 | [illegible] |
| 309 | 127 | 6.60 | 198 | 10.29 | 126 | 6.55 | 0 | 0.0 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 310 | 44 | 1.52 | 81 | 2.63 | 94 | 3.03 | 1 | 0.03 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 311 | 202 | 10.75 | 227 | 12.05 | 172 | 9.16 | 3 | 0.15 | 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 312 | 340 | 2.27 | 706 | 4.71 | 80 | 0.54 | 9 | 0.06 | 548 | 3.66 | 441 | 2.94 | 2520 | 16.87 | 189 | 1.26 |
| 313 | 135 | 0.57 | 446 | 1.87 | 35 | 0.15 | 16 | 0.07 | 42 | 0.18 | 137 | 0.57 | 11891 | 49.50 | 127 | 0.53 |
| 314 | 167 | 13.65 | 175 | 14.34 | 85 | 6.98 | 0 | 0.0 | 0 | 0.0 | 49 | 3.99 | 484 | 39.72 | [illegible] | [illegible] |
| 315 | 77 | 0.12 | 206 | 0.32 | 69 | 0.11 | 94 | 0.15 | 371 | [illegible] | 2990 | [illegible] | [illegible] | [illegible] | 755 | [illegible] |
| 316 | 177 | 0.72 | 795 | 3.25 | 34 | 0.14 | 344 | 1.41 | 617 | [illegible] | [illegible] | [illegible] | 1387 | [illegible] | 326 | [illegible] |
| 317 | 360 | 6.10 | 753 | 12.74 | 90 | 1.52 | 120 | 2.03 | 129 | [illegible] | 81 | [illegible] | 1276 | 21.60 | 105 | [illegible] |
| 318 | 51 | 0.69 | 241 | 3.32 | 6 | 0.08 | 717 | 9.85 | 69 | 0.95 | 20 | 0.27 | 1110 | 15.25 | 95 | 1.30 |
| 319 | 419 | 3.32 | 820 | 6.49 | 149 | 1.18 | 149 | 1.18 | 147 | [illegible] | 271 | [illegible] | [illegible] | [illegible] | 156 | [illegible] |
| 320 | 371 | 0.91 | 981 | 2.40 | 168 | 0.41 | 189 | 0.46 | 807 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 321 | 189 | 0.54 | 464 | 1.32 | 121 | 0.34 | 10 | 0.03 | 175 | 0.50 | 1170 | 3.32 | 1000 | [illegible] | 178 | 0.50 |
| 322 | 212 | 0.78 | 444 | 1.64 | 196 | 0.72 | 1372 | 5.08 | 300 | 1.11 | 335 | 1.24 | 1950 | 7.22 | 248 | 0.92 |
| 323 | 960 | 1.84 | 1743 | 3.35 | 477 | 0.92 | 583 | 1.12 | 665 | 1.28 | 503 | 0.96 | 5771 | 11.08 | 628 | 1.21 |
| 324 | 34 | 0.16 | 129 | 0.62 | 7 | 0.04 | 90 | 0.43 | 140 | 0.67 | 119 | 0.57 | 4180 | 19.98 | 186 | 0.89 |
| 326 | 99 | 0.61 | 300 | 1.95 | 52 | 0.34 | 85 | 0.55 | 130 | 0.85 | [illegible] | [illegible] | 2457 | 15.92 | 178 | [illegible] |
| 400 | 477 | 1.81 | 154 | 0.59 | 633 | 2.39 | 24227 | 91.68 | 8 | 0.03 | 102 | 0.39 | 56 | 0.21 | 498 | 1.88 |

1979 LANDSAT LAND COVER AND 1970 CENSUS TRACTS
UNIVERSITY OF WASHINGTON REMOTE SENSING APPLICATIONS LABORATORY
JULY 20 1979 LAND COVER FROM CLASSIFICATION OF LANDSAT SCENE 21640-18140
DIGITAL PROCESSING USING THE VICAR SOFTWARE AT WSUCSC

| CENSUS TRACT NUMBER | CROPLAND | | BRUSH (DRY) | | TALL SHRUB | | DECIDUOUS FOREST | | MIXED FOREST | | CONIFEROUS FOREST | | OLD CONIFER FOREST | | REGROWTH FOREST | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. | ACRES | PCT. |
| 256 | 58 | 2.91 | 116 | 5.82 | 458 | 22.96 | 187 | 9.39 | 44 | 2.21 | 172 | 8.64 | 2 | 0.09 | 0 | 0.0 |
| 257 | 57 | 2.87 | 48 | 2.76 | 299 | 17.26 | 162 | 9.36 | 25 | 1.46 | 168 | 9.69 | 3 | 0.16 | 0 | 0.0 |
| 258 | 90 | 3.98 | 39 | 1.74 | 527 | 23.32 | 112 | 4.97 | 24 | 1.08 | 108 | 4.76 | 0 | 0.0 | 0 | 0.0 |
| 259 | 197 | 9.11 | 48 | 2.20 | 160 | 7.38 | 32 | 1.47 | 48 | 2.23 | 6 | 0.26 | 0 | 0.0 | 0 | 0.0 |
| 260 | 0 | 0.0 | 0 | 0.0 | 108 | 7.98 | 37 | 2.70 | 110 | 8.18 | 4 | 0.28 | 0 | 0.0 | 0 | 0.0 |
| 261 | 0 | 0.0 | 2 | 0.17 | 105 | 9.76 | 4 | 0.35 | 99 | 9.24 | 7 | 0.61 | 0 | 0.0 | 0 | 0.0 |
| 262 | 76 | 4.14 | 26 | 1.43 | 84 | 4.60 | 26 | 1.43 | 52 | 2.86 | 5 | 0.26 | 0 | 0.0 | 0 | 0.0 |
| 263 | 0 | 0.0 | 1 | 0.07 | 35 | 2.56 | 9 | 0.71 | 44 | 3.34 | 6 | 0.43 | 0 | 0.0 | 0 | 0.0 |
| 264 | 0 | 0.0 | 0 | 0.0 | 62 | 5.49 | 13 | 1.16 | 102 | 9.07 | 4 | 0.33 | 0 | 0.0 | 0 | 0.0 |
| 265 | 0 | 0.0 | 0 | 0.0 | 9 | 3.18 | 5 | 1.59 | 20 | 6.69 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 266 | 0 | 0.0 | 0 | 0.0 | 7 | 2.84 | 2 | 0.71 | 7 | 2.84 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 267 | 0 | 0.0 | 2 | 0.25 | 6 | 0.76 | 31 | 4.19 | 69 | 9.39 | 75 | 10.15 | 0 | 0.0 | 0 | 0.0 |
| 268 | 0 | 0.0 | 1 | 0.10 | 20 | 2.13 | 0 | 0.0 | 15 | 1.62 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 269 | 0 | 0.0 | 0 | 0.0 | 4 | 2.07 | 0 | 0.0 | 3 | 1.55 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 270 | 0 | 0.0 | 0 | 0.0 | 18 | 3.42 | 0 | 0.0 | 22 | 4.14 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 271 | 0 | 0.0 | 0 | 0.0 | 31 | 7.73 | 22 | 9.39 | 15 | 3.75 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 272 | 0 | 0.0 | 1 | 0.12 | 83 | 10.43 | 1 | [illegible] | 17 | 2.11 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 273 | 0 | 0.0 | 1 | 0.21 | 53 | 6.51 | 4 | [illegible] | 27 | 3.00 | 4 | 0.41 | 0 | 0.0 | 0 | 0.0 |
| 274 | 0 | 0.0 | 2 | 0.22 | 27 | 3.25 | 2 | [illegible] | 41 | 4.93 | 2 | 0.22 | 0 | 0.0 | 0 | 0.0 |
| 275 | 0 | 0.0 | 0 | 0.0 | 2 | 0.32 | 0 | [illegible] | 4 | 0.80 | 1 | 0.16 | 0 | 0.0 | 0 | 0.0 |
| 276 | 0 | 0.0 | 32 | 4.66 | 4 | 0.55 | 16 | [illegible] | 47 | 6.86 | 209 | 30.59 | [illegible] | 0.55 | 0 | 0.0 |
| 277 | 495 | 2.08 | 222 | 0.93 | 3371 | 14.18 | 5927 | 24.96 | 2261 | 9.43 | 5114 | 21.32 | 64 | 0.27 | 0 | 0.0 |
| 278 | 0 | 0.0 | 39 | 5.59 | 6 | 0.80 | 20 | 2.80 | 106 | 15.05 | 67 | 9.56 | 3 | 0.40 | 0 | 0.0 |
| 279 | 0 | 0.0 | 7 | 0.74 | 8 | 0.95 | 5 | 0.53 | 37 | 4.34 | 9 | 1.06 | 0 | 0.0 | 0 | 0.0 |
| 280 | 0 | 0.0 | 4 | 0.75 | 20 | 3.94 | 1 | 0.19 | 19 | 3.25 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 281 | 0 | 0.0 | 2 | 0.29 | 39 | 6.05 | 6 | 0.86 | 25 | 6.07 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 282 | 31 | 4.91 | 4 | 0.60 | 43 | 6.85 | 22 | 3.57 | 20 | 6.43 | 0 | 0.45 | 0 | 0.0 | 0 | 0.0 |
| 283 | 365 | 16.43 | 20 | 0.88 | 139 | 6.28 | 112 | 5.06 | 45 | 2.02 | 15 | 0.67 | 0 | 0.0 | 0 | 0.0 |
| 284 | 10 | 0.48 | 8 | 0.39 | 44 | 2.06 | 9 | 0.44 | 19 | 0.88 | 1 | 0.04 | 0 | 0.0 | 0 | 0.0 |
| 285 | 0 | 0.0 | 1 | 0.09 | 48 | 4.65 | 15 | 1.46 | 126 | 12.31 | 6 | 0.55 | 0 | 0.0 | 0 | 0.0 |
| 286 | 0 | 0.0 | 39 | 2.41 | 85 | 5.23 | 59 | 3.62 | 195 | 11.27 | 161 | 9.89 | 0 | 0.0 | 0 | 0.0 |
| 287 | 11 | 1.69 | 21 | 3.09 | 54 | 8.16 | 4 | 0.56 | 8 | [illegible] | 17 | 2.53 | 0 | 0.0 | 0 | 0.0 |
| 288 | 104 | 1.10 | 40 | 1.96 | 334 | 16.25 | 67 | 3.28 | 17 | 0.82 | 53 | 2.59 | 2 | 0.09 | 0 | 0.0 |
| 289 | 20 | 1.30 | 29 | 2.51 | 225 | 19.42 | 30 | 2.59 | 3 | 0.24 | 22 | 1.94 | 0 | 0.0 | 0 | 0.0 |
| 290 | 37 | 1.99 | 24 | 1.99 | [illegible] | 22.07 | 82 | 4.65 | 17 | 0.94 | 127 | 7.11 | 0 | 0.0 | 0 | 0.0 |
| 291 | 144 | 8.73 | 24 | 1.49 | 249 | [illegible] | [illegible] | 5.53 | 5 | 0.29 | 37 | 2.21 | 0 | 0.0 | 0 | 0.0 |
| 292 | 1038 | 15.85 | 66 | 1.01 | 461 | 7.03 | 123 | 1.87 | 16 | 0.24 | 157 | 2.40 | 1 | 0.01 | 0 | 0.0 |
| 293 | 199 | 4.65 | 57 | 1.33 | 1164 | 26.68 | 416 | 9.69 | 74 | 1.72 | 360 | 8.41 | 4 | 0.09 | 0 | 0.0 |
| 294 | 165 | 6.66 | 32 | 1.29 | 470 | 19.99 | 256 | 10.37 | 30 | 1.21 | 97 | 3.97 | 0 | 0.0 | 0 | 0.0 |
| 295 | 109 | 5.24 | 26 | 1.98 | 487 | 22.50 | 79 | 3.80 | 7 | 0.30 | 69 | 3.34 | 0 | 0.0 | 0 | 0.0 |
| 296 | 391 | 7.66 | 25 | 1.78 | 493 | [illegible] | 254 | 9.65 | 44 | 1.67 | 173 | 6.59 | 0 | 0.0 | 0 | 0.0 |
| 297 | 173 | 6.98 | 87 | 3.51 | 394 | 15.89 | 101 | 4.08 | 20 | 0.79 | 242 | 9.78 | 0 | 0.0 | 0 | 0.0 |
| 298 | 452 | 12.12 | 79 | 2.11 | 345 | 14.60 | 373 | 9.98 | 51 | 1.38 | 197 | 5.29 | 7 | 0.22 | 0 | 0.0 |
| 299 | 113 | 4.96 | 113 | 4.06 | 717 | 25.68 | 253 | 9.05 | 32 | 1.14 | 379 | [illegible] | 5 | 0.17 | 0 | 0.0 |
| 300 | 83 | 2.01 | 83 | 2.97 | 618 | 22.05 | 193 | 6.88 | 25 | 0.90 | 741 | 8.59 | 1 | 0.03 | 0 | 0.0 |
| 301 | 8 | 2.27 | 79 | 4.10 | 352 | 19.14 | 58 | 4.19 | 48 | 2.77 | 128 | 9.26 | 0 | 0.0 | 0 | 0.0 |
| 302 | 41 | 1.77 | 70 | 3.10 | 286 | 12.16 | 90 | 5.41 | 4 | 0.25 | 52 | 3.52 | 1 | 0.05 | 0 | 0.0 |
| 303 | 281 | 3.37 | 261 | 3.28 | 1682 | 21.10 | 895 | 11.22 | 78 | 0.97 | 838 | 10.51 | 7 | 0.08 | 0 | 0.0 |
| 304 | 115 | 3.97 | 519 | 8.84 | 1904 | 30.92 | 440 | 7.54 | 69 | 1.19 | 1116 | 19.12 | 25 | 0.43 | 0 | 0.0 |
| 305 | 405 | 15.14 | 29 | 0.87 | 95 | 2.39 | 45 | 1.01 | 0 | 0.0 | 16 | 0.40 | 0 | 0.0 | 0 | 0.0 |
| 306 | 25 | 2.86 | [illegible] | [illegible] | 122 | 14.92 | 22 | 2.54 | 1 | 0.11 | 43 | 4.87 | 0 | 0.0 | 0 | 0.0 |
| 307 | [illegible] | 1.03 | 7 | 1.81 | 155 | 7.69 | 0 | 0.0 | 0 | 0.0 | 2 | 0.52 | 0 | 0.0 | 0 | 0.0 |
| 308 | 106 | 4.90 | 20 | 0.91 | 147 | 6.81 | 10 | 0.48 | 0 | 0.0 | 13 | 0.61 | 0 | 0.0 | 0 | 0.0 |
| 309 | 174 | 9.02 | 5 | 0.24 | 196 | 10.14 | 81 | 4.22 | 15 | 0.78 | 34 | 1.75 | 0 | 0.0 | 0 | 0.0 |
| 310 | 89 | 2.30 | 292 | 9.32 | 432 | 16.07 | 278 | 8.92 | 216 | 6.99 | 814 | 26.34 | 22 | 0.73 | 185 | 5.99 |
| 311 | [illegible] | [illegible] | 128 | 5.12 | 190 | 10.60 | 178 | 3.38 | 35 | 1.84 | 280 | 14.88 | 8 | 0.45 | 43 | 2.29 |
| 312 | 264 | 1.76 | 767 | 5.11 | 2696 | 17.92 | 2077 | 13.86 | 797 | 5.32 | 3150 | 21.02 | 127 | 0.85 | 276 | 1.84 |
| 313 | 1194 | 5.00 | 378 | 1.58 | 2671 | 11.19 | 3180 | 13.32 | 1150 | 4.82 | 2074 | 8.69 | 55 | 0.23 | 344 | 1.44 |
| 314 | 137 | 11.20 | 0 | 0.0 | 72 | 5.90 | 44 | 3.63 | 4 | 0.31 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 315 | 429 | 0.67 | 2901 | 4.50 | 1802 | 5.80 | 7741 | 12.01 | 8390 | 13.02 | 26519 | 41.15 | 5097 | 7.91 | 2589 | 4.02 |
| 316 | 88 | 0.36 | 1149 | 5.70 | 2274 | [illegible] | 5782 | 23.64 | 3021 | 12.36 | 6540 | 26.75 | 639 | 2.61 | 765 | 3.13 |
| 317 | 186 | 3.15 | 384 | 6.50 | 1463 | 24.64 | 346 | 5.82 | 67 | 1.14 | 559 | 9.46 | 9 | 0.15 | 0 | 0.0 |
| 318 | 66 | 0.90 | 132 | 1.81 | 1554 | 21.35 | 1349 | 18.53 | 363 | 4.99 | 1465 | 20.12 | 43 | 0.59 | 0 | 0.0 |
| 319 | 179 | 1.42 | 410 | 3.25 | 2704 | 21.42 | 3189 | 25.26 | 654 | 5.18 | 1837 | 14.55 | 67 | 0.53 | 0 | 0.0 |
| 320 | 135 | 0.28 | 1297 | 3.88 | 9782 | 11.72 | 8223 | 20.89 | 4586 | 11.24 | 12906 | 31.62 | 2258 | 5.53 | 227 | 0.56 |
| 321 | 51 | 0.19 | 1406 | 2.99 | 6701 | 16.02 | 6377 | 16.39 | 4410 | 12.51 | 15429 | 43.77 | 1672 | 4.74 | 1069 | 3.03 |
| 322 | 231 | 0.86 | 937 | 3.10 | 2350 | 10.01 | 7997 | 29.22 | 3965 | 14.68 | 5743 | 21.26 | 161 | 0.60 | 338 | 1.25 |
| 323 | 1461 | 2.77 | 1326 | 2.55 | 8256 | 15.85 | 12172 | 23.37 | 5948 | 11.42 | 11348 | 21.78 | 271 | 0.52 | 0 | 0.0 |
| 324 | 786 | 3.76 | 694 | 3.13 | 1353 | 6.46 | 6245 | 29.83 | 2709 | 12.95 | 3581 | 17.12 | 113 | 0.54 | 600 | 2.87 |
| 326 | 193 | 1.23 | 395 | 5.68 | 1053 | 10.75 | 2982 | 19.43 | 1660 | 10.80 | 4073 | 26.49 | 365 | 2.37 | 277 | 1.80 |
| 400 | 2 | 0.01 | 122 | 0.46 | 25 | 0.10 | 9 | 0.04 | 70 | 0.27 | 61 | 0.23 | 32 | 0.17 | 0 | 0.0 |